QUALITY ASSURANCE PROJECT PLAN
PRE-DESIGN PHASE
WAUKEGAN HARBOR SITE
WAUKEGAN, ILLINOIS

1.0 PROJECT DESCRIPTION

1.1 Introduction

The purpose of the Quality Assurance Project Plan (QAPP) for the pre-design phase of the work (in the Work Plan), Appendix __ to the Consent Order, for the Waukegan Harbor Site (Site) in Waukegan, Illinois is to set forth the prime responsibilities and prescribe the necessary procedures required to assure that the project is executed in a manner consistent with the National Oil and Hazardous Substance Contingency Plan and with generally accepted and approved quality assurance objectives, that data generated is precise, accurate, representative, comparable, and complete, and that remedial action measures, specified in the work plan, will be completed as specified.

This QAPP provides guidance and specifications to assure that:

1. All field determinations and results regarding sampling and analysis are valid through the implementation of preventive maintenance, equipment calibration, and approved analytical protocols;

2. Sampling is conducted using sample tracking systems and chain-of-custody procedures which properly identify samples being collected and control those samples from field collection through analysis and data reduction;

3. Records are produced and retained as documentary evidence of the quality of samples collected and analyzed, the validity of applied procedures, and the completeness of the work performed;

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4. Generated data is validated and appropriately used in calcula-
    tions;

5. Calculations, evaluations, and decisions completed or deduced
    during the execution of the pre-design phase are accurate,
    appropriate, and consistent with the objectives of this Plan;

6. Construction activities are completed to the specifications
    described within this Plan.

The requirements of this QAPP are applicable to the pre-design activities
of all participants in the remedial action at the Waukegan Harbor site in
Waukegan, Illinois. This QAPP will address all anticipated activities
necessary to execute the Work Plan pre-design activities as approved by the
U.S. EPA.

1.2 Project Summary: Waukegan Harbor Site

1.2.1 Project Background

The Waukegan Harbor Site (Site) is located near the intersection of Grand
Avenue and Sheridan Road on the west shore of Lake Michigan in Waukegan,
Illinois, about 37 miles north of Chicago and 10 miles south of the
Wisconsin state border.

The presence of high levels of PCBs in soil and harbor sediments in the
vicinity of the OMC plant was discovered in 1976. From 1962 to 1976, OMC
used a hydraulic fluid in the die-casting works that contained PCBs. OMC
has advised U.S. EPA that 10 to 15 percent of all PCBs purchased may have
escaped through floor drains and past an oil interceptor system. The floor
drains discharged to Waukegan Harbor and the North Ditch drainage. The
harbor area discharge was located in the western end of Slip No. 3, and the

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north property discharge was in the Crescent Ditch. No remediation of the site soils has occurred to this date.

1.2.2 Project Objectives

The objectives of this QAPP are to assure proper field and laboratory procedures are employed in implementation of the pre-design investigation set forth in the Work Plan.

1.2.3 Major Task Summary

1.2.3.1 Pre-Design Work Plan

Major activities to be undertaken during the course of the pre-design phase of the Work Plan and addressed by this QAPP include the following:

1. Soil sample collection and physical analysis;

2. Installation of piezometers in the Silurian bedrock;

3. Surveying of site features, including the location and elevation of soil samples, ground water monitoring wells, sediment sampling locations, topographic contours of the ground surface, and piezometric contours of the ground water surface.

1.2.4 Reports

Quarterly status/progress reports will be prepared and submitted to U.S. EPA which summarize the results of all sampling and/or tests and present all other data generated during the preceeding quarter. Work Plan activities will be reviewed and the status of all pending or completed activities will be indicated. Analytical and/or other documentation which support the

summaries presented in the quarterly reports will be available and fur-
nished to the U.S. EPA upon request.

Periodically, interim technical reports may be prepared to collate data and
summarize the progress of the Work Plan, present conclusions affecting the
scope or direction of continuing Work Plan activities. These reports will
be scheduled and identified in the quarterly status/progress reports.

2.0 PROJECT ORGANIZATION AND RESPONSIBILITIES

2.1 Organization

Quality assurance and control activities must occur at all levels of the organization in order to consistently produce effective and correct efficient solutions to a broad range of technical problems. The activities of the QAPP Team for the Work Plan must remain independent of the activities of the project task force in order to assure that procedures and protocols outlined in the Work Plan are carried out in a manner consistent with U.S. EPA guidelines.

2.2 Responsibility for Quality Assurance/Quality Control

Responsibility for quality assurance and quality control depends upon the project organization assembled to execute the work and on the maintenance of the principle lines of communication between members of the organization. Figure 1 shows the proposed task force for the implementation of the Work Plan and the lines of communication between various key individuals. The responsibilities of the Canonie task force and related managerial departments are summarized below.

2.2.1 Project Manager

The project manager is responsible for maintaining a clear definition of and adherence to the scope, schedule, and budget of the project. As a part of this responsibility, he will:

1. Serve as the on-site communication link with the U.S. EPA;

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2. Provide immediate direction to staff involved in the completion of tasks outlined in the Work Plan;

3. Supervise all work by Canonie and its subcontractors;

4. Maintain budgetary and schedule surveillance of the work and regularly advise the Technical Project Director of the progress of the Work Plan.

2.2.2 Technical Project Director

The technical project director is responsible for the staffing and overall administration of the project. As part of his QA/QC responsibilities, he will:

1. Maintain the QAPP;

2. Indicate the types of QA/QC records to be retained as a permanent part of the project file;

3. Provide for QA/QC audits of the work of task force members;

4. Approve reports and material for release to the U.S. EPA and IEPA, and other external organizations;

5. Approve task plans and operating procedures related to the project.

2.2.3 Project Engineer/Project Scientist

The project engineer is responsible for the implementation of the Work Plan field activities, initial data acquisition, health and safety aspects of

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field activities, and for the proper selection and execution of procedures which have been accepted for use in the Work Plan. As part of his QA/QC responsibilities, he will:

1. Provide personal direction of technicians or subcontractors executing Work Plan data gathering tasks and performing construction activities;

2. Review the effectiveness of procedures and suggest changes which will enhance or more efficiently accomplish the objectives of the Work Plan;

3. Assist in the collection of samples so that sampling remains representative of actual field conditions;

4. Assist in the maintenance of budgetary and scheduling surveillance;

5. Administer the regular maintenance of equipment utilized in the Work Plan to prevent unnecessary equipment failures and project delays caused thereby.

6. Assist in the preparation of reports, submittals, and presentations to assure that data and conclusions accurately reflect observed conditions in the field;

2.2.4 Task Leaders

The task leaders within the project task force are responsible for specific engineering, scientific, and analytical operations required to accomplish identified project objectives. As part of this responsibility, task leaders will:

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1. Initiate, develop, and check subtask plans, procedures, support services and products;

2. Identify safety hazards and ensure that the associated risks are reduced to acceptable levels;

3. Supervise and participate in operations, analyses, data collection, and data reduction;

4. Maintain samples, sample identification, and analytical equipment;

5. Generate required QA/QC records and reports;

6. Implement corrective actions identified by QA/QC reports.

2.2.5 Quality Review Team

The Quality Review Team reports directly to the corporate officer in charge. The team is responsible for on-going surveillance of project activities to ensure conformance to this Plan and to evaluate the effectiveness of its requirements. The team has access to any Canonie personnel or project subcontractors, as necessary, to resolve quality assurance/quality control problems. The team has authority to recommend that work be stopped when the manner in which that work is being conducted appears to jeopardize project quality. As part of this responsibility, the team will:

1. Monitor the correction of quality control problems, and alert other task leaders where similar problems may exist or might occur;

2. Report to the corporate officer in charge concerning the quality of the work, the procedures utilized, and the services provided in relation to the stated objectives of the project;

3. Provide for retention of QA/QC records;

4. Participate in QA/QC audits;

5. Recommend changes, where appropriate, to improve the effectiveness of project procedures or the procedures identified in this Plan;

6. Review proposed additions and/or changes to this Plan.

The Quality Review Team is directed by the Quality Assurance Coordinator, who is responsible for evaluating and approving this Plan; scheduling and conducting quality assurance/quality control audits; providing QA/QC reports to the corporate officer in charge, the project manager, and the technical project director on the results of audits by the Quality Assurance Team and the necessity of preventive or corrective actions; and developing and initiating preventative and corrective actions, as required, in conjunction with the project manager and technical project director.

2.2.6 Support Departments

Canonie's accounting department will be responsible for the financial administration of subcontracts, the control of the payment of invoices, and for overall budgetary matters.

Canonie's technical support department will provide services in the areas of graphics, reproductions, word processing, data processing, and staffing. Canonie's soils laboratory will be the soils testing laboratory for the soil samples obtained during the pre-design work.

3.0 QUALITY ASSURANCE OBJECTIVES

3.1 General

The quality of measurements made and data acquired during the Work Plan
process will be determined by the following characteristics: accuracy,
precision, representativeness, completeness, and comparability. Specific
objectives for each characteristic are established to develop sampling
protocols and identify applicable documentation, sample handling proce-
dures, and measurement system procedures. These objectives are established
based on site conditions, objectives of the project, and knowledge of
available measurement systems. The subsequent use of these measurements in
calculations and evaluations is also subject to aspects of this Plan as
described in the following sections.

Canonie will collect all soil samples and direct all field measurements in
completing the work presented in the Work Plan. Sample collection and
field handling will be in accordance with the sampling and sample handling
protocols established in this Plan. All soil samples will be analyzed at
Canonie's soils laboratory, located in Porter, Indiana. The quality
assurance program developed for and utilized at Canonie's analytical
laboratory is presented in Appendix A.

3.2 Representativeness

Measurements will be made so that analytical results are as representative
of the actual field conditions as possible. Sampling protocols will be
utilized to assure that samples collected are representative of the media
present in the field. Sample handling protocols, including such tasks as
storage, transportation, and preservation, will be used to protect the
representativeness of the samples gathered during the project. Proper

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documentation in the field and the laboratory will establish that protocols have been followed and that sample identification as well as integrity have been preserved.

The field sampling program, presented in the Work Plan, describes the samples which are currently planned for collection, the location of the sampling, the types of samples to be collected, and the types and number of analyses to be performed on the samples.

3.3 Precision and Accuracy

Precision is the characteristic which reflects the ability to replicate a previously obtained value using identical testing procedures, while accuracy is the characteristic which reflects the ability to obtain a value which equals, or approaches within certain predetermined limits, the true value of a certain phenomenon. Each of these two characteristics are addressed in all data gathering and reporting conducted by Canonie. Data quality objectives for precision and accuracy are established for each major parameter to be measured during the project. These objectives are based upon prior experience in executing remedial activities for wastes similar to those present or anticipated at this site, on prior knowledge of the capabilities of the measurement system to be employed during activity at the site, and on the limitations which are presented in execution of the task. The precision and accuracy requirements for certain data gathering and reporting activities may vary based upon the anticipated use of the information. For example, the precision and accuracy requirements of data gathered during surveying to locate ground water monitoring wells will not be as strict as the requirements imposed on analytical data, which is used to establish whether treated ground water is clean enough to discharge.

In general, the precision and accuracy requirements for the Work Plan program will be met by assuring that at least ten percent of the samples

gathered for analytical evaluation in each matrix type (i.e., soil, water, etc.) during each sampling episode are duplicates, so that field precision may be evaluated. Since standard sampling procedures are stipulated for all sampling episodes, no additional duplicates are required due to changes in sampling team composition. In the laboratory, ten percent of the samples of each matrix will be analyzed as replicates to evaluate laboratory precision. Duplicate and replicate samples will be chosen at random, unless the criticalness of the sampling would suggest duplicate sampling or replicate sampling to be appropriate.

Calculations performed with the data gathered or generated during the project are also checked for accuracy by the task leader or his designee, and precision, i.e., the comparability of calculation techniques between various tasks, is assured through review by the quality assurance team.

Accuracy of field measured pH will be evaluated through comparison of instrument readings taken on standard buffer solutions. Accuracy will be established by obtaining readings which do not vary from the standardized solution value by ± 0.05 pH units. Field measurements will be recorded to the nearest 0.05 pH units.

Accuracy of the field conductivity meter will be assured by daily calibration verification with a standardized solution of potassium chloride, purchased from the manufacturer of the meter or from a laboratory chemical supply house. If instrument readings vary from the standardized value by more than five percent (5%), the conductivity meter will be recalibrated or replaced.

Instruments which are factory calibrated will be considered accurate if the most recent calibration occurred within the previous 12-month period and the instrument readings do not appear to be in obvious error. Measurement

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precision for all field instrumentation will be estimated by periodically
(1 per 10 samples) completing duplicate testing of samples in the field.

3.4 Completeness

The characteristic of completeness is a measure of the amount of valid data
obtained compared to the amount that was specified to be obtained under
normal conditions. The amount of valid data specified is established based
on the measurements required to accomplish project objectives. The extent
of completeness must be reviewed on a relative basis for sample collection
activities, since the required amount of valid data anticipated prior to
sampling episodes may not accurately define the amount of data necessary to
render a correct decision. Completeness of data handling systems is
described in Sections 9, 12, and 13.

3.5 Comparability

The characteristic of comparability reflects both internal consistency of
data collected with regard to a single parameter and an expression of data
in units which are consistent with the units which data, gathered by other
organizations measuring the same parameter, are presented. Comparability
of data gathering and measuring procedures should also be addressed if data
gathered is to be reliably compared. Thus, the characteristic of compara-
bility implies the personnel involved in data acquisition and reduction
must operate measurement systems within the calibrated range of the parti-
cular instrument as well as utilize analytical methodologies which produce
comparable results.

When comparison of data sets indicates certain values within one or more
sets are not consistent with the totality of the data acquired, these
values, known as "outliers", must be reassessed prior to utilization in the
decision-making process. Utilization of statistical analysis is often

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required to define whether the "outliers" represent significant values
which require recognition in the decision-making process.

3.6 Quality Assurance/Quality Control Objectives

The QA/QC objectives for the pre-design investigations are:

1. To collect soil samples that are representative of the soil types
   present at the site;

2. To determine the variation in the in-situ coefficient of permea-
   bility of natural impermeable formations with depth;

3. To collect, document, and prepare data for the final design activ-
   ities that is accurate and reflects the variations likely in
   geologic materials.

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4.0 PRE-DESIGN PROGRAM

4.1 Field Sampling Program

4.1.1 Introduction

The specific tasks that comprise the Field Sampling Program and the steps to execute the tasks are described in Section 2.0 of the Work Plan. The purpose of this section is to define the minimum standards for performing the field activities of the Pre-Design Program.

All drilling, soil sampling, and piezometer construction activities will be supervised by a qualified engineering or geologist. The engineer/geologist will summarize, daily on a field activity log, the progress made towards completing the activities in the Field Sampling Program. Also, any procedures or materials that are not in compliance with the Work Plan or QAPP will be documented and the corrective action taken will be noted. A daily field activity log is included in Appendix B.

4.1.2 Soil Sampling

4.1.2.1 Standard Split-Spoon Samples

Standard split-spoon samples will be taken in accordance with the requirements of ASTM D-1586. A copy of the procedures is attached in Appendix C. The split-spoon may be driven a total of 24 inches at the discretion of the field engineer. If the split-spoon is driven 24 inches to maximize sample recovery, the second and third six-inch blow counts will be used to calculate the penetration resistance (N). Boring logs will be maintained, by the field engineer, to record each sample taken. As a minimum, the following information will be recorded on the boring logs:

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1. Sample number;

2. Type of sampler;

3. Sample interval (ft.);

4. Blow count;

5. Sample recovery;

6. Preliminary USCS classification by visual inspection;

7. Unconfined compressive strength (Qu), if sample is clay, as deter-
   mined by a pocket penetrometer;

8. Depth of contact between soil strata;

9. Soil description and remarks.

A copy of a boring log legend and boring log are included in Appendix D.

All soil recovered in the split-spoon will be retained in sealed glass
jars. As a minimum, the top of the jar will be labeled, with indelible
ink, with the following information:

1. Job number;

2. Soil boring number;

3. Sample number;

4. Sample interval;

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5. Number of jars containing sample (example: jar 1 of 3);

6. Sample date.

4.1.2.2 Pitcher Barrel Samples

Pitcher barrel samples will be retrieved over 24-inch sample intervals. Shelby tube samples will be acceptable if the penetration resistance is less than 20 blows per foot or more than 18 inches of undisturbed sample can be recovered.

Once a sample has been taken and the tube removed from the pitcher barrel assembly, the ends of the tubes will be coated with non-shrinking wax. Plastic caps will be placed over the ends of the tube and taped in place. The tube wall and top cap will be labeled with the following information as a minimum:

1. Job number;

2. Soil boring number;

3. Sample number;

4. Sample interval;

5. Sample recovery (inches);

6. Top of tube;

7. Sample date.

The samples will be preserved and transported in accordance with
ASTM D4220. Specifically, the samples will be kept in a vertical position
and kept at a temperature between 40° F and 100° F until the tubes are
shipped to the soils laboratory. A copy of ASTM D4220 is included in
Appendix C.

4.1.2.3 Harbor Sediment Samples

Approximately 25 gallons of sediment will be obtained from various loca-
tions in the Upper Harbor and Slip No. 3. The sediment samples will be
recovered using a sampler dredge similar to the sampler shown in Appendix
E. Since the samples will not be subjected to chemical analysis, the
sampler may be constructed of other materials approved by the field
engineer. Special care will be taken to assure the samples retrieved are
representative of the harbor sediments and the finer fraction is not washed
out during sampling. If the finer fraction of the sediments is washed out,
the sample will be returned to the harbor and another sample retrieved.

4.1.3 In-Situ Permeability Tests

Two types of in-situ permeability tests will be performed in nine of the
soil borings located on the slurry wall alignments. The first type will be
designated as a vertical permeability test and the second type will be
designated as a horizontal permeability test. The vertical test will
utilize a pneumatically inflated seal (packer) located in the boring casing
at a depth equal to the existing ground water level. The boring casing
will be driven at least one foot into the clay till, the soil plug removed
by rotary wash, and a permeability test conducted by pressurizing the water
inside the casing and measuring the flow of water into the borehole. The
measured permeability will be representative of the vertical coefficient of
permeability. The laboratory permeability tests performed on pitcher

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barrel samples will be compared to the field permeability tests from this method.

The horizontal test method will place the pneumatically operated seal (packer) in the bottom of the casing with an extending unlined borehole approximately three (3) feet below the end of the casing. After the packer is inflated inside the casing, the three foot test cavity will be pressurized and flow measurements recorded. The measured permeability will be representative of the horizontal coefficient of permeability. The horizontal test is the best available method for measuring the in-situ horizontal permeability.

Three borings along the slurry wall alignments will be selected for each of the three containment areas for the permeability tests. The vertical permeability test will be performed in one boring for each containment area, and the horizontal permeability test will be performed in two borings for each containment area. The field permeability data obtained from each boring will be used to design the depth of the slurry wall penetration into the underlying clay till such that the flow of water beneath the wall is less than or equal to the flow of water through the slurry wall.

The procedure for drilling the soil borings and performing the in-situ permeability tests is as follows:

For the horizontal test;

1. The borings will be advanced from the ground surface to the surface of the clay till by rotary wash drilling in a 6-inch diameter casing. Standard split-spoon samples will be recovered at 5-foot intervals.

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2. HW steel casing (4-inch I.D.) will be lowered into the hole and driven at least one-foot into the till to assure an adequate seal is obtained between the till and the casing.

3. The drilling fluid will be flushed from the 4-inch casing with potable water.

4. The boring will be advanced by rotary wash methods with a 2-15/16 inch diameter tricone roller bit reaming the borehole remaining after each split spoon sample. Split-spoon samples will be obtained continuously through the clay till.

5. When the desired test cavity length (3 feet) is obtained, the borehole will be flushed with potable water to remove silt and sediments.

6. The packer assembly will be set in the hole such that the packer remains in the 4-inch casing but is at the end of the casing and the unlined soil borehole creates the test cavity. The packer is then inflated to seal the test zone.

7. The testing apparatus will consist of a pressurized reservoir of water capable of maintaining a constant pressure in the test cavity, while measuring the flow of water through the test cavity.

8. The test cavity pressures will be calculated to prevent hydrofracturing of the clay till as follows:

$$P_{max} = P_o + P_{allow} + H_L$$

Where:

P_{max} = Maximum Test Cavity Pressure

P_0 = Hydraulic Pressure due to the Static Water Level

P_{allow}= Excess hydraulic pressure allowed due to the weight of overburden (0.5 psi per foot of depth to test section)

H_L = Friction head losses in the test apparatus valves and piping

Example:

Assume: H_L = 0, no friction head losses due to valves and piping.

Given:

Depth to ground water = 5 feet
Depth to top of clay = 25 feet
Depth to bottom of test cavity = 29 feet

P_0 = (29-5) x (62.4 pcf/144 in^2/ft^2) = 10.4 psi
P_{allow} = 0.5 psi/ft x 29 ft.   = <u>14.5</u> psi

P_{max} = 24.9 psi

Use 24 psi for testing.

9. The horizontal permeability test will be run at 1/2 P_{max}, 3/4 P_{max}, P_{max}, 3/4 P_{max}, and 1/2 P_{max} to allow hydraulic pressures to dissipate uniformly and check for problems with the packer seal.

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The flow into the test cavity will be recorded at 5-minute intervals. After one hour, if the flow rate over the last three (3) successive 5-minute intervals varies by less than 10 percent the test at that pressure is complete. If not, the test will continue until the flow rate over three (3) successive 5-minute intervals varies by less than 10 percent. The data is recorded on a field permeability test form attached in Appendix J.

10. The pressure versus flow is plotted to check for evidence of problems such as leakage around the packer, erosion of the test zone, and clogging of fissures. A high quality test will produce a linear relationship of pressure to flow with little difference between the pressurization toward P_{max} and depressurization away from P_{max}.

11. The horizontal permeability is calculated as shown in Appendix J on Figure 8-10.

12. If the horizontal permeability for the first 3-foot test section is equal to or less than 1×10^{-7} cm/sec, then no additional permeability tests will be performed in that boring. The packers and permeability apparatus will be removed and the borehole will be drilled and sampled to completion (20-foot penetration into the clay till or as required).

13. If the horizontal permeability in the test section is greater than 1×10^{-7} cm/sec, then the field engineer will determine, as discussed in the Work Plan, if the measured horizontal permeability combined with the measured vertical permeability provides a barrier to flow equivalent to the 3-foot wide slurry wall.

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14. If the field engineer's determination indicates the in-situ soil in the first test section does not provide an adequate flow barrier, the boring will be advanced one-foot and the packer and permeability apparatus replaced. The permeability test will be repeated as before after recalculating P_{max} for the new test section.

15. The boring will be advanced in one foot increments and the permeability test repeated until the field engineer determines, as discussed in the Work Plan, the horizontal and vertical permeabilities in the in-situ soils will provide a barrier to flow that is equivalent to the 3-foot slurry wall.

16. The borehole will be backfilled by tremie grouting with cement/ bentonite grout before removing the casings.

For the vertical permeability test;

1. The borings will be advanced from the ground surface to the surface of the clay till by rotary wash drilling in a 6-inch-diameter casing. Standard split-spoon samples will be recovered at 5-foot intervals.

2. HW steel casing (4-inch I.D.) will be lowered into the hole and driven at least one foot into the till to assure an adequate seal is obtained between the till and the casing. The HW casing will consist of a single piece of pipe with no joints below the ground water level and a beveled end for driving into the clayey till.

3. The drilling fluid will be flushed from the 4-inch casing with potable water and the clay plug will be removed by rotary wash

drilling. The water will be pumped or bailed from the casing to within two feet above the existing ground water level.

4. The single packer assembly will be set in the 4-inch casing such that the packer is at the existing ground water level. The packer is then inflated to seal the casing.

5. The testing apparatus will consist of a pressurized reservoir of water capable of maintaining a constant pressure in the test cavity while measuring the vertical flow of water through the soil plug in the bottom of the casing.

6. The test cavity pressures will be calculated to prevent hydrofracturing as follows:

$$P_{max} = P_o + P_{allow} + H_L$$

Where: P_{max} = Maximum test cavity pressure
P_o = Hydraulic pressure due to static water level
P_{allow} = Excess hydraulic pressure allowed due to weight of overburden (0.5 psi per foot of depth to test section)
H_L = Friction head losses in test apparatus valves and piping

Example:

Assume: H_L = 0, no friction head losses due to valves and piping

Given:

Depth to ground water   =   5 feet
Depth to top of clay   =   25 feet
Depth to bottom of casing = 26 feet

$$P_0 = (26-5) \times (62.4 \text{ pcf}/144 \text{ in}^2/\text{ft}^2) = 9.2 \text{ psi}$$
$$P_{allow} = 0.5 \text{ psi/ft} \times 26 \text{ ft} = \underline{13.0} \text{ psi}$$
$$P_{max} = 22.1 \text{ psi}$$

CAUTION: Because the packer is set at the ground water level, P_0 is already applied to the test cavity.

Therefore, the testing apparatus gauges only need to record the P_{allow}. The calculations for permeability however are dependent on P_{max}.

7. The single packer permeability test will be run at $1/2 \, (P_{allow} + H_L)$, $3/4 \, (P_{allow} + H_L)$, $P_{allow} + H_L$, $3/4 \, (P_{allow} + H_L)$, $1/2 \, (P_{allow} + H_L)$ to allow hydraulic pressures to dissipate uniformly and check for problems with the packer seals or casing seal. The flow into the test cavity will be recorded at 5-minute intervals. After one hour, if the flow rate over the last three (3) successive 5-minute intervals varies by less than 10 percent the test at that pressure is complete. If not, the test will continue until the flow rate over three (3) successive 5-minute intervals varies by less than 10 percent. The data is recorded on a field permeability test form attached in Appendix J.

8. The pressure versus flow is plotted to check for evidence of problems such as leakage around the packer, erosion of soil through the test zone, and clogging of fissures. A high quality

test will produce a linear relationship of pressure to flow with little difference between the pressurization toward $P_{allow} + H_L$ and depressurization away from $P_{allow} + H_L$.

9. The vertical permeability is calculated as shown in Appendix J on Figure 8-11 and will be compared to the laboratory permeability test results on pitcher barrel samples.

10. The boring will be completed with continuous split-spoon sampling to the specified depth of penetration into the clay till. Between samples the borehole will be reamed with a 2-15/16 inch diameter tricone roller bit.

11. The borehole will be backfilled by tremie grouting with cement/bentonite grout after removing the casings.

4.1.4 Rock Core Drilling

All rock coring will be performed with an NX (2-5/32 in.) diamond tip core barrel assembly. The rock coring will be performed in accordance with the requirements of ASTM D-2113. A copy of the specification is attached in Appendix C. All recovered cores will be placed in commercial plastic, cardboard, or shop-made wooden boxes, and the beginning and end of each core run will be properly marked with the blocks provided. Rock core logs will be maintained by the field engineer to record each core obtained. As a minimum the following information will be recorded on the core log:

1. Sample number;

2. Length of core run;

3. Core size;

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4. Coring pressure (PSI);

5. Rate of core advance (ft./min.);

6. Percent core recovery;

7. RQD;

8. Number of fractures per foot;

9. Bedding;

10. Hardness;

11. Description of rock core.

A copy of a rock core legend and rock core log are included in Appendix F.

4.1.5 Piezometers

The installation procedures for piezometers are described in the Work Plan. Therefore, only material requirements will be described in this section.

The installation of each piezometer will be logged on an observation well diagram. All well construction information will be recorded to the nearest tenth of a foot. A copy of a blank observation well diagram and a typical well detail diagram are included in Appendix G.

4.1.5.1 Piezometers in Silurian Bedrock

4.1.5.1.1 PVC Screens

Piezometer screens will be machine-slotted, one-inch-diameter Schedule 80
PVC, with at least three rows of slots. The slot openings will be
.01 inches for all piezometers. The screen section will be threaded for
attachment to the riser pipe and the bottom of the screen will be provided
with a threaded PVC plug. The screen and 10 feet of riser pipe above the
screen zone will be free of ink and any other markings.

4.1.5.1.2 PVC Riser Pipe

Riser pipe for the piezometers will consist of Schedule 80 PVC pipe meeting
ASTM D-1785 with flush joint threads. A copy of the specification is
included in Appendix C.

4.1.5.1.3 Sand Pack

Sand pack is the material placed in the annular space around the well
screen. The pack shall be uniformly graded sand or gravel, comprised of
hard, durable particles which have been washed with potable water and
screened. The sizing of the particles shall be determined by the soil type
encountered in the zone to be monitored. The particle size of the pack
shall be at least 4 times the D15 size (15 percent of the soil is finer
than this dimension) of the soil in the monitored zone and shall be no more
than 4 times the D85 size (85 percent of the soil is finer than this
dimension) of the soil in the monitored zone. The sand pack shall be free
of all organic matter and shall not contain detectable concentrations of
any chemical constituents. The sand pack shall be furnished in unopened
bags or pails.

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4.1.5.1.4 Bentonite Seals

A bentonite seal is used in the annular space above the piezometer screen.
The bentonite seal will consist of Volclay grout. Volclay grout is a high
solid bentonite based clay grout. The grout will be placed using the
tremie method. The Volclay grout will consist of the following
proportions:

1. 52 pounds of Volclay grout (includes 2 pounds of initiator);

2. 24.4 gallons of fresh water.

The Volclay grout will be provided to the job site in full, unopened bags.
The Volclay grout, initiator, and water will be mixed to a uniform
consistency, free of lumps. A mud balance test will be run on each batch
prior to placement, and the slurry weight must achieve a minimum of
9.4 pounds per gallon at time of placement. The grout will be installed by
the tremie method.

4.1.5.1.5 Concrete

Concrete is required for capping the annular space in piezometers and
simultaneously providing a solid base for supporting the piezometer riser
pipe protective cover.

Concrete shall be provided to the job site in full, unopened bags such as
Sakrete, or in a premixed state from a local concrete supplier.

4.1.5.1.6 Placement of Protective Cover

A carbon steel pipe, having an inside diameter of at least 1.33 times the outside diameter of the piezometer's riser pipe, shall be set concentrically around the riser pipe and into the concrete cap. The bottom of the well protector shall be submerged at least three feet into the concrete, and shall extend at least six inches above the top of the riser pipe. The concrete which is forced out of the borehole due to the placement of the well protector shall be carefully removed so as to prevent "mushrooming" of the concrete at the ground surface, which tends to promote lifting of the well casing and the well protector during frost heave conditions. The well protector shall be maintained plumb and concentric with the riser pipe until the concrete has set. Temporary braces may be required to maintain the well protector in the proper vertical position. A locking cap shall be secured to the top of the well protector pipe to prevent unauthorized entry into the well.

4.1.5.2 Piezometers in Shallow Aquifers

4.1.5.2.1 PVC Screens

The material requirements for PVC screen in shallow aquifer piezometers is the same as for the piezometers in Silurian bedrock, Section 4.1.5.1.1.

4.1.5.2.2 PVC Riser Pipe

Riser pipe for the piezometers will consist of Schedule 80 PVC pipe meeting ASTM D-1785 with flush joint threads. A copy of the specification is included in Appendix C.

4.1.5.2.3 Sand Pack

The material requirements for sand packs in shallow aquifer piezometers are the same as for the piezometers in Silurian bedrock, Section 4.1.5.1.3.

The shallow aquifer sand may be used for the sand pack if the engineer determines that it is acceptable.

4.1.5.2.4 Concrete

The material requirements for concrete in shallow aquifer piezometers is the same as for the piezometers in Silurian bedrock, Section 4.1.5.1.5.

4.1.5.2.5 Placement of Protective Cover

The requirements for placement of protective cover in shallow aquifer piezometers is the same as for the piezometers in Silurian bedrock, Section 4.1.5.1.6.

4.1.6 Developing Existing Monitoring Wells

4.1.6.1 Cleaning of Equipment and Material

All pumps to be used in development, purging, or pumping of wells at the site shall be steam cleaned and all wetted parts, hoses, and valves flushed thoroughly with water from the source approved by the field engineer. Pumps which leak or otherwise may introduce chemical constituents into the well, sampled water, or aquifer shall not be used. Electrical lines to submersible pumps shall meet all applicable electrical code standards. Electrical lines to submersible pumps may be attached to the discharge pipe or hose of the pump by stainless steel or plastic fasteners which grip by means of a

mechanical action only. No electrical tape shall be used to attach electrical lines to the discharge pipe or hose.

Compressors utilized in the development, purging, or pumping of wells at the site shall be equipped with an operable oil trap and in-line air filter. The oil trap and filter shall be checked by the field engineer prior to each day's use. The oil trap and filter must be capable of removing entrained oil from the compressed air to prevent introduction of chemical constituents into the sample water or the ground water.

If bladder pumps are utilized and powered by compressed nitrogen, the nitrogen gas shall be pressure regulated at the tank and shall pass through an in-line oil trap and filter before it enters the well or pump. The source of nitrogen gas shall be indicated in the daily log for the site activities.

4.1.6.2 Existing Well Development

Existing monitoring wells shall be developed, by pumping or other means of evacuating the well casing, in order to remove the sediments within the casing, any trapped soil fines in the gravel pack and soil formation just outside the pack and to produce a representative sample of the water in the formation.

Well development may be accomplished through the use of submersible, bladder, jet, or suction pumps. Pumps must be fully operational, meet applicable electrical or other code provisions, and must be thoroughly cleaned in accordance with procedures set forth in Section 4.1.6.1. Pump capacity shall be rated at three to five gallons per minute. Pumps shall be operated to remove water from the well casing continuously for at least five minutes without pumping the well dry. As an alternative to pumping, an air lift may be utilized to evacuate and surge the well. Where the nature of the

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formation or recharge to the well makes development of the well infeasible using pumps, bailers may be utilized.

Well development shall continue until representative formation water is obtained. Representative formation water shall be defined as water which is generally free of sediment, and has a stable pH, temperature, and specific conductivity when measured within a period of ten minutes. In general, well development shall proceed for at least two hours, unless prior experience suggests that a shorter well development period results in the production of formation water which is representative. Well development water will be discharged onto the ground near the well.

4.1.7 Cement/Bentonite Grout

Cement/bentonite grout is required for backfilling completed soil borings. The grout will consist of the following proportions per bag of Portland cement:

1. 7.3 gallons of clean water;

2. 4.0 pounds of sodium bentonite powder;

3. 94 pounds of Type I Portland cement.

The cement and bentonite will be provided to the job site in full, unopened bags. The bentonite powder and water will be mixed first. Cement will not be added to the mixture until the bentonite and water is mixed to a uniform consistency, free of lumps. At the discretion of the field engineer, the amount of cement can be increased. The grout will be installed by the tremie method.

4.2 Laboratory Testing Program

The specific tests that comprise the laboratory testing program and the
number of tests required is described in Section 2.2 of the Work Plan. The
purpose of this section is to define the standards to which each laboratory
test will comply.

All laboratory testing will be supervised by a qualified engineer. Care
will be taken in handling all samples so that the integrity of the sample
is not damaged. When obtaining a sample of harbor sediments, from the
sample container, special care will be taken to assure that the finer
fraction of the sediments is included in the sample.

4.2.1 Moisture Content Analysis

All moisture content analysis will be performed in accordance with
ASTM D2216. All data will be recorded on appropriate laboratory forms. A
copy of ASTM 2216 and a laboratory form are included in Appendices C and H,
respectively.

4.2.2 Mechanical Sieve Analysis

All mechanical sieve analysis will be performed in accordance with
ASTM D422. Hydrometer analysis will not be performed as part of a mechani-
cal sieve analysis. All data will be recorded on appropriate laboratory
forms and summarized on semi-logarithmic grain-size curves. A copy of ASTM
D422, a laboratory form, and grain-size curve are included in Appendices C,
H, and H, respectively.

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4.2.3 No. 200 Sieve Wash

The amount of material that is finer than a No. 200 sieve will be determined in accordance with ASTM D1140. All data will be recorded on appropriate laboratory forms. A copy of ASTM D1140 and a laboratory form are included in Appendices C and H, respectively.

4.2.4 Standard Proctor Test

All standard Proctor tests will be performed in accordance with ASTM D698. Care will be taken to assure that each layer, in the test, is comprised of the same amount of soil and the same compactive effort is applied to each layer. All laboratory data will be recorded on appropriate laboratory forms. A copy of ASTM D698 and a laboratory form are included in Appendices C and H, respectively.

4.2.5 Consolidation Tests

All consolidation tests will be performed in accordance with ASTM D2435. The consolidation apparatus will be located in the lab so that disturbance due to vibration, movement of laboratory personnel, etc. is minimized. All consolidation data will be recorded on appropriate laboratory forms. A copy of ASTM D2435 and laboratory forms is included in Appendices C and H, respectively.

4.2.6 Atterberg Limits

All Atterberg limits tests will be performed in accordance with ASTM D4318. All test data will be recorded on appropriate forms. A copy of ASTM D4318 and laboratory forms are included in Appendices C and H, respectively.

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4.2.7 Permeability/Compatibility Test

The constant head permeability test for fixed-soil samples will be per-
formed in a modified triaxial consolidation apparatus. For this method, a
flexible rubber membrane encloses the soil sample. Water is pressurized on
the outside of the flexible membrane to hold the membrane against the side
of the soil sample. Water from the site is introduced under pressure at
the bottom of the sample and allowed to move vertically through the sample
until full saturation is achieved. A copy of the triaxial cell permeabil-
ity log sheet and calculation sheet are included in Appendix H.

The procedure for the permeability test is as follows:

1.   The length and diameter of the sample is measured both before and
     after the testing for permeability.

2.   The sample is enclosed within a synthetic flexible membrane with a
     porous stone on both the top and the bottom ends.

3.   Drain lines are attached to both the top and bottom caps and the
     triaxial cell is assembled. The annulus between the cell wall and
     sample is flooded with de-aired tap water.

4.   Both the inflow and outflow measuring burettes and their attaching
     lines are filled with the water being utilized.

5.   The cell pressure (pressure confining the soil sample within the
     rubber jacket) is increased slowly to 40 psig. The pressures on
     the influent and effluent burettes are then set to create a dif-
     ferential pressure across the sample. The influent burette pres-
     sure is set at 35 psig and the effluent pressure is set at

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15 psig, creating a differential pressure across the sample of 20 psig. This is equivalent to 46 feet of water pressure.

6. The flow in and out of the sample is monitored on a daily basis. The samples will be tested for a period adequate to displace one to three sample pore volumes.

7. The permeability is calculated from the dimensions, pressure differential, and the flow rates for each sample.

The permeability for each sample is determined from Darcy's law for steady-state laminar flow. The rearrangement of Darcy's law used to calculate the permeabilities of the sample is:

$$k = q \; l/(hA)$$

Where:
- k = permeability (cm/sec)
- q = flow rate (cm^3/sec)
- l = length (cm)
- h = pressure differential (cm)
- A = total cross sectional area of the sample that is perpendicular to the flow (cm^2)

The permeability values are plotted as a function of the displaced pore volumes. Examination of the relationship between permeability and pore volume displacement is the basis for determination of the compatibility of the soil/bentonite backfill, and natural soils with on-site ground water and with water that is in contact with PCB sediments.

The permeability tests for the pitcher barrel samples and recompacted clay samples will be performed as above, but different pressures will be used. The cell pressure will be 52 psig, the influent pressure will be 50 psig, and the effluent pressure will be 30 psig.

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5.0 CUSTODY OF SAMPLES

An established program of sample chain-of-custody procedures, that is followed during sample collection and handling activities in both the field and laboratory operations, shall be established to assure that sample integrity is maintained and data generated through the analysis of the samples is applicable to evaluation of the site. The program is designed to assure that each sample is accounted for at all times. To maintain the highest degree of control in sample handling, preprinted labels will be utilized so that all necessary information is retained with the sample, and chain-of-custody records and shipping manifests will be employed to maintain control over access to and destination of samples after shipment from the location of sample collection. Additionally, proper completion of field sample logs, accession books, tracking sheets, and extraction logs by appropriate field and laboratory personnel will provide for thorough monitoring of the samples from collection through analysis and final report generation.

The sample identification, custody, and monitoring procedures shall assure that:

1. All samples collected are uniquely labeled for identification purposes throughout the analytical process;

2. Samples are correctly analyzed and that results are traceable to field records;

3. Important sample characteristics are preserved;

4. Samples are protected from loss, damage, or tampering;

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5. Any alteration of samples (e.g., filtration, preservation, or damage due to shipment or other processes) is documented;

6. A record of sample integrity and analytical fate is established for legal purposes.

5.1 Sample Monitoring Forms

The use of the indicated forms listed above accomplishes one or more of the specific objectives of sample custody, identification, or control. The use of each of the listed forms is discussed below.

5.1.1 Sample Log

The sample log is completed in the field by the individual physically in charge of the sample collection. The sample log correlates the assigned sample bottle designation to a specific well or sample location or other distinguishing feature or attribute (i.e., dummy sample, replicate sample, purge evaluation sample, etc.). The sample log also contains information concerning day and time of sampling, type, location, and depth for wells, water depth in the well, purge volume, purge water temperature, pH, and conductivity as a function of time, procedures utilized to preserve the sample for analysis, and the sequence in which sampling was completed. Other relevant information, such as weather conditions, may also be included.

5.1.2 Chain-of-Custody Record

The chain-of-custody record is completed in the field by the individual physically in charge of the sample collection. The chain-of-custody record may be completed contemporaneously with the sample log or prior to the

shipment of samples to the laboratory. The chain-of-custody record con-
tains information on the date of sample collection, the sampler, the pro-
ject name and number, laboratory project number, the number of containers
of each sample being shipped, and an itemization of the analyses requested
for each sample together with any remarks about the sample prior to ship-
ment. The chain-of-custody record is enclosed with the samples after it
has been signed by the sampler. The record is then signed each time pos-
session of the samples changes, with the signature of the person relin-
quishing and receiving the sample, as well as the time of exchange being
indicated on the record. A sample copy of a chain-of-custody form is set
forth on Attachment III of Appendix A.

5.1.3 Accession Book

The accession book is maintained at the receiving analytical laboratory by
the sample custodian. When samples arrive from the field, each container
is assigned a laboratory number which is then logged into the accession
book. Other important information entered into the accession book includes
the name of the shipping firm or person who delivered the samples to the
laboratory, the date received and the individual taking custody, the
container size and any comments related to possible mishandling, abuse or
obvious damage to the shipping container or contents, the name of the
client, the date and time of sample collection, the samplers initials, and
the site from which the samples originated. The accession book becomes the
permanent record of all samples received by the laboratory for analysis. A
sample page from the accession book is presented on Attachment V of
Appendix A.

5.1.4 Tracking Sheets

The tracking sheets are developed at the time the samples are logged into
the accession book. Each sample received at the analytical laboratory has

its own unique tracking sheet. The tracking sheet contains the date the sample was taken, received by the laboratory, prepared for analysis, and finally analyzed. Results of analysis as well as dilution of the sample or any other conditions used are also noted. Tracking sheets are utilized for presumptive as well as confirming analysis. Final reports are generated from the information on the tracking sheets. The tracking sheet for each sample, as well as any notes, chromotographic charts, and atomic absorption printouts are permanently filed in the records of the laboratory. A sample tracking sheet is presented on Attachment IV of Appendix A.

5.1.5 Extraction Log

Various types of analyses require that sample extraction and subsequent volume reduction occur. Each sample which undergoes this process is recorded in the extraction log with information on all conditions which existed during the creation of the final extract. Typical information includes the sample number, initial volume, final volume, date the extraction/volume reduction was produced, analyst performing the work, the methodology utilized, and any comments about the nature of the sample. The extraction log is a permanent record maintained by the analytical laboratory.

The flow of samples and analytical data within the Canonie analytical laboratory is illustrated on Figure 3. Omitted for clarity are procedures which involve calibration of instrumentation for each analytical run and verification of instrument detection limits, which are conducted on a quarterly basis.

5.2 Reagent Documentation

Written documentation of reagents utilized in the analytical laboratory is maintained in a reagent record book. Information maintained includes the

date the stock is made, the analyst preparing the stock, the weight or volume of all materials used in the creation of the stock, the source of the chemical, and the source lot number. The record includes information for stock standards, intermediate stock, and quality assurance stock. U.S. EPA protocols shall be followed in the creation and testing of all stock. All stock bottles are clearly labeled with the exact contents of the bottle, the concentration, the date of creation, the expiration date, and the analyst who created the stock. Reagents are stored at conditions appropriate for each stock, and are discarded after standard permissible holding times have been exceeded or if contamination or decomposition of the stock is evident.

For general inorganic analysis, Analytical Reagent (AR) grade reagents are utilized. Metal analysis performed via atomic absorption spectroscopy employs reagents and solvents of spectroquality. For organic analysis, the minimum purity shall be AR grade. For high pressure liquid chromatography (HPLC), HPLC grade solvents shall be used. Where requested analysis requires more stringent grades of reagents, those reagents shall be utilized. All base stock for the creation of reagents in the laboratory are purchased from reputable suppliers and are of the requisite standard purity. Typical commercial suppliers which may be used for the purchase of base stock and standards include Supelco and Chem Service, along with Foxboro, J. T. Baker, Fisher Scientific, Aldrich, and American Scientific. Several sources are used so that a contamination or defect in one source can be detected, by comparison against another source, before a great deal of false analytical results are reviewed and published. The use of multiple source in stocking the laboratory's chemical needs, therefore, promotes additional quality assurance throughout the analytical process. Stock and standard solutions are tracked in a manner illustrated on the forms presented as Attachments VII, VIII, and IX of Appendix A.

5.3 Packing and Shipping

In addition to sample collection and preservation requirements, especially the maintenance of sample temperature at 4 degrees C until extraction or analysis, samples should be packed and shipped properly to maintain the health and safety of sample transporters. Guidelines for packing and shipping of samples are included in Appendix I.

6.0 CALIBRATION PROCEDURES AND FREQUENCY

6.1 Calibration Procedures for Laboratory Equipment

Equipment shall be calibrated in accordance with procedures presented in the appropriate ASTM specifications.

6.2 Calibration Procedures and Frequency for Field Instruments

Equipment utilized in the field shall be calibrated prior to each day's use. The procedures for each piece of equipment which will be utilized are set forth below. If other instruments are used, the manufacturer's calibration procedures shall be followed.

6.2.1 Thermometer

Using a National Bureau of Standards-approved thermometer, immerse both the field thermometer and NBS-approved thermometer into a beaker of water and note any differences for the field probe.

Recalibrate the field probe as necessary.

6.2.2 Specific Conductance Meter

Calibrate meter and probe using the calibration control and the conductance calibration line on the meter dial or a standard solution of known conductance.

Turn the function switch to read conductivity x 10 and then depress the cell test button, noting the deflection. If the needle falls more than two percent of the reading, clean the probe and retest.

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Using at least two potassium chloride buffer solutions which will most likely bracket the range of expected conductivity, note accuracy of the meter and probe and clean probe if necessary.

6.2.3 pH Meter

Place electrodes and the manufacturer's supplied buffer solutions in a water bath at the temperature of the water to be sampled. After temperature equilibrium has been established, measure the temperature and adjust the temperature compensation knob for the temperature indicated.

If refillable electrode probes are used, remove the electrode cap and check that probe solution is above the full mark.

Immerse the probe in the pH 7 buffer solution and adjust the calibration control to read pH 7.

Remove the probe, rinse with distilled water and then immerse in either the pH 4 or pH 10 buffer solution, depending on the expected pH of the sample solution.

If the pH meter does not register the correct pH for the buffer solution tested, adjust the calibration knob on the back of the instrument so that the meter reads the correct pH as defined by the buffer solution tested.

After rinsing the probe, insert the probe into the sample to be tested and allow the probe to come to equilibrium with the sample water prior to recording the readout.

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7.0 ANALYTICAL PROCEDURES

7.1 Selection of Parameters

The selection of parameters for the project is made through an evaluation of existing data and an analysis of data needs with respect to the project objectives. The parameters of interest are designated in the pre-design phase of the Work Plan, and particular parameters to be addressed in each sample are noted.

7.2 Selection of Procedures

Procedures to be utilized in accomplishing the activity described in the pre-design phase of the Work Plan shall be in accordance with methods, protocols, and procedures set forth in Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Method 8080, U.S. Environmental Protection Agency, 1982, Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater, PB83-201796, Method 608, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1982, and relevant materials testing methods approved by the American Society of Testing and Materials (ASTM), including the following listed here that are included in Appendix C:

    ASTM D1586 Method for Penetration Test and Split-Barrel Sampling of Soils

    ASTM D4220 Practices for Preserving and Transporting Soil Samples

    ASTM D2113 Practice for Diamond Core Drilling for Site Investigation

    ASTM D1785 Specification for Polyvinyl Chloride (PVC) Plastic Pipe, Schedules 40, 80, and 120

    ASTM D2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

    ASTM D422   Method for Particle-Size Analysis of Soils

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ASTM D1140 Method for Amount of Material in Soils Finer than the No. 200 (75-um) Sieve

ASTM D698 Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb. (2.49-kg) Rammer and 12-in. (305-mm) Drop

ASTM D2435 Method for One-Dimensional Consolidation Properties of Soils

ASTM D4318 Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

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8.0 DATA REDUCTION, VALIDATION, AND REPORTING

Data reduction is the process of converting measurement system outputs to an expression of the parameter which is consistent with the comparability objective identified in Section 3.5 of this plan. Calculations completed during data reduction of analytical results shall be in accordance with approved U.S. EPA analytical methods and procedures.

Field data collection and validation will follow the process illustrated on Figure 2. Once the data is obtained, it is reviewed and assessed for overall adequacy by the Operations Coordinator. If it is determined that the initial data collection activity, or a portion thereof, did not provide adequate data, the activity will be repeated.

Calculations performed during data reduction shall be reviewed by the chemist performing the analysis, by the engineer/scientist/technician collecting data in the field, or by the engineer/scientist evaluating data in the laboratory, prior to the release of any data reporting, thus assuring that reporting errors are kept to a minimum. Laboratory review of data reduction is illustrated on Figure 3.

Analytical results reported for each sample shall be verified to assure proper identification by comparing the original sample collection logs with the chain-of-custody forms and the various laboratory log books. Based upon the results of this validation procedure, the laboratory shall certify that the results are in compliance with the quality assurance objectives for accuracy and precision. Upon certification by the laboratory manager, the reported values shall be received and reviewed by the technical staff and the Quality Assurance Coordinator, if deemed necessary. Analytical data shall be presented in a format illustrated by Figure 4.

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Field or analytical data entered into the corporate computer database for
storage, analysis, or report generation, shall be initially submitted to
the Manager of Data Processing, or his designee. Data submitted for entry
has been checked and verified by the engineer, scientist, chemist, or
technician as being accurate and complete, and meeting the quality
assurance criteria established for the phase of work in which the data was
developed. Data is then entered into the computer by data entry operators
using standardized entry forms developed especially for the type of data
under consideration.

After entry of the data into the computer, a hard copy printout of the data
is generated and the printout is compared directly with the original data
sheets. A data entry operator who was not involved in the original entry
of the data to the computer reviews the hardcopy printout. Each entry is
reviewed, and inaccurate entries are highlighted. After review is com-
plete, the hardcopy printout is returned to the original data entry opera-
tor and the noted inaccuracies are corrected. A final printout of the data
is generated by the computer and the corrected version of the database is
reviewed. After all corrections have been made to the database, the origi-
nal data sheets are stamped "POSTED", and filed in the office's central
file.

Data, information, or designs, submitted to the drafting department for
development, are initially prepared by the engineer or scientist charged
with the responsibility for creation of a graphical representation. The
sketch or graphic representation is then reviewed by the engineer or scien-
tist originating the material and the chief draftsman for format, intent,
and consistency with prior work. The drawing is then assigned a unique
project drawing number, the number and title of the drawing is entered into
the drafting department log, and a draftsman is assigned to formally devel-
op the drawing. After completing the initial presentation of the drawing,
a paper check print is produced for review by the originating engineer or

scientist. All information on the check print is reviewed and approved information is highlighted with a yellow highlighter marker, while incorrect information, changes, or additions are noted in red ink. The check print is then returned to the draftsman for correction, and a final check print is issued for review. Upon approval of the final check print, the originating engineer or scientist signs and dates the mylar original. The drawing is then reviewed by the task leader or project manager for consistency with project objectives, and then the task leader or project manager signs and dates the original mylar.

Revisions to previously approved mylar drawings are submitted to the drafting department on paper prints of the original mylar. Revisions are made to the mylar, with a review process occurring as noted above for original work. When the revisions are finally approved, a notation of the revision scope is noted in the margin of the drawing, and the dated, revised drawing is then signed by the individual approving the revision as presented.

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9.0 INTERNAL QUALITY CONTROL ANALYTICAL LABORATORY

This section is included for analysis of PCBs for the water treatment assessment. The internal quality control standards for the laboratory are presented in Appendix A. The following sections from Appendix A are appropriate and relevant for the laboratory analytical work for the pre-design phase.

Section 1	Introduction
Section 2	Personnel
Section 4	Sample Custody
Section 5	Calibration and Maintenance Procedures Pages 16, 24, 25, 26, and 28
Section 6	Analytical Procedures, Page 37
Section 7	Data Review and Reporting
Section 8	Quality Control
Section 9	Establishment of Acceptable Limits
Section 10	Acceptance Criteria and Problems
Section 11	Analysis of External Reference Samples
Section 12	Review of Analytical Results by the Quality Assurance Officer

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10.0 AUDITS

Quality assurance audits are performed to assure and document that quality control measures are being utilized to provide data of acceptable quality and that subsequent calculations, interpretation, and other project outputs are checked and validated. The quality assurance coordinator or a member of the quality assurance review team will visit the site periodically and unannounced to assure that the designated control procedures set forth in this document are practiced.

At least one system and performance audits may be conducted by the Quality Assurance Coordinator. The Quality Review Team will conduct project audits of calculations, interpretations, and reports which are based on the measurement system outputs.

10.1 Systems Audit

At least one systems audit may be conducted on all components of measurement systems to determine proper selection and utilization. The systems audit shall include evaluation of both field and laboratory procedures.

10.1.1 Organization and Personnel

The project organization is reviewed for compliance with the proposed organization and for clarity of assigned responsibility. Personnel assigned to the project will be reviewed to determine that assigned responsibility, skill, and training of the personnel are properly matched to the requirements of the project. The Technical Project Director will maintain firsthand knowledge of his/her team's capabilities and will

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discuss the organization's efficiency with the Quality Assurance Coordinator. Assigned personnel may be interviewed by the Quality Assurance Coordinator during an audit.

10.1.2 Facilities and Equipment

The audit will address whether field tools, analytical instruments, and construction equipment selected and meet the requirements specified by the project objectives stated in this Plan and other project work plans. Equipment and facilities provided for personnel health and safety will also be evaluated.

10.1.3 Analytical Methodology

Routine external performance evaluations as well as blind internal performance evaluations will be conducted in accordance with standard procedures of the U.S. EPA. A review of analytical methodology in regard to the data requirements for the project will also be performed. An on-site observation of analyst technique, data reduction, and recordkeeping may be performed if determined necessary. Periodic review of the precision and accuracy of data shall also be performed.

10.1.4 Sampling and Sample Handling Procedure

An audit of scheduled samples versus samples collected versus samples received for analysis shall be performed. Field documentation will be reviewed. If deemed necessary, a site visit will be made to assure that designated control procedures are practiced during sampling activities.

10.1.5 Data Handling

During a systems audit, the Quality Assurance Coordinator will review data handling procedures with the Technical Project Director and Task Leaders. Accuracy, consistency, documentation, and appropriate selection of methodologies will be discussed.

10.2 Performance Audit

These audits are intended primarily for analytical and data generation systems. The laboratory will complete its own performance evaluations as discussed in Appendix A.

10.3 Project Audit

Project audits encompass the aspects of both the systems audit and the performance audit. The project audit typically occurs at least twice for a short-term project and more often during long-term projects. Timing is keyed to the systems involved and the project objectives.

10.4 QA Audit Report

A written report of the Quality Assurance audit may be prepared to include:

1. An assessment of task force's status in each of the major project areas;

2. Clear statements of areas requiring improvement or problems to be corrected. Recommendation and assistance will be provided regarding proposed corrective actions or system improvements. If no action is required, the report will state that the QA audit was satisfactorily completed.

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3.   A timetable for any corrective action required;

4.   A follow-up to assure that recommendations have been implemented.

11.0 PREVENTIVE MAINTENANCE

Preventive maintenance of all field equipment proceeds routinely before each sampling event; more extensive maintenance is performed on the basis of hours in use.

Laboratory equipment is maintained on a regular, scheduled basis. This maintenance is documented in the laboratory records book for each instrument. Emergency repair or scheduled manufacturer's maintenance is provided under repair and maintenance contracts with factory representatives.

12.0 DATA ASSESSMENT

The purpose of data quality assessment is to assure that data generated under the program is accurate and consistent with project objectives. The quality of data will be assessed based on the precision, accuracy, consistency, and completeness of the data that is measured or generated.

Data quality assessment will be conducted in three phases:

12.1 Phase 1

Prior to data collection, sampling and analytical procedures will be evaluated in regard to their ability to generate the appropriate technically acceptable information required to achieve project objectives. This Quality Assurance/Quality Control Plan meets this requirement by establishing project objectives defined in terms of parameters, analytical methods, and required performance levels.

12.2 Phase 2

During data collection, results will be assessed to assure that the selected procedures are efficient and effective, and that the data generated provides sufficient information to achieve project objectives. Precision and accuracy of measurement systems will also be evaluated. In general, evaluation of data will be based on performance audits and review of completeness objectives.

Documentation will include:

1. Number of replicate samples collected;

2. Number of replicate, spike, and field blank samples analyzed;

3. Use of historical data and its reference;

4. Identification of analytical method used;

5. Evaluation of the data package, which will include:

    o   Initial calibration and calibration verification.
    o   Continuing calibration verification after every 20 samples
        for elemental parameters and daily for semi-volatiles.
    o   Spiked sample analysis after every 10 samples for elemental
        parameters and after every 20 samples for semi-volatiles.
    o   10 percent preparation blank analysis.
    o   One duplicate sample analysis for every 10 samples.

The technical director of Canonie's laboratory will be responsible for any
additional evaluation required of analytical data packages.

12.3 Phase 3

Throughout the data collection activities, an assessment of the adequacy of
the database generated in regard to completing the project objectives will
be undertaken. Recommendations for improved quality control will be devel-
oped, if appropriate. In the event that data gaps are identified, the
Quality Assurance Coordinator or Quality Review Team may recommend the
collection of additional raw data to fully support the project's findings
and recommendations.

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13.0 CORRECTIVE ACTION

Corrective or preventive action is required when potential or existing conditions are identified that may have an adverse impact on data quantity or quality. Corrective action could be immediate or long-term. In general, any member of the program staff who identifies a condition adversely affecting quality can initiate corrective action by notifying in writing his or her supervisor and the Quality Assurance Coordinator. The written communication will identify the condition and explain how it may affect data quality or quantity. Corrective action in the field is the responsibility of each individual of the on-site staff, with review of procedures to be used occurring prior to sampling episodes and a check of the procedures implemented taking place after the sampling episode is completed.

Corrective actions with regard to laboratory analyses are the responsibility of the designated laboratory. In general, situations which may require corrective action are identified through the analysis of travel blanks and blanks retained in the laboratory, which would show any potential contamination of samples by incorrect laboratory preparation procedures or through the shipping phase, if it existed. These blanks are included in each sample set shipped to the laboratory, providing a constant check on these two potential sources of error. During analysis, the typical procedure which the chemist utilizes in testing the samples involves the analysis of a laboratory blank, a calibration sample, a laboratory blank, several field samples, a live spike, a spiked laboratory blank, and several duplicates and/or replicates. Overall quality control in the laboratory is maintained by utilizing quality control standards which are prepared independently from calibration standards. Preparation of quality control standards may be by a chemist not directly involved in the preparation of the calibration standards, by an outside laboratory, or by a manufacturer/supplier of laboratory supplies. The acceptance or rejection of analytical data is

contingent upon the results of analysis presented for the quality control
and calibration standards. The plotting of quality control data on a chart
allows for continued tracking of quality control procedures and results,
with this information as well as all analytical results retained in the
files for future reference and review.

13.1 Immediate Corrective Action

This type of corrective action is usually applied to spontaneous, non-
recurring problems, such as an instrument malfunction. The individual who
detects or suspects nonconformance to previously established criteria or
protocol in equipment, instruments, data, methods, etc., will immediately
notify his/her supervisor. The supervisor and the appropriate task leader
will then investigate the extent of the problem and take the necessary
corrective steps. If a large quantity of data is affected, the task leader
must prepare a memorandum to the Project Manager, the client, and the
Quality Assurance Coordinator. These individuals will collectively decide
on a course of action to correct the deficiencies while the project con-
tinues to proceed. If the problem is limited in scope, the Task Leader
will decide on the corrective action measure, document the solution in the
appropriate workbook, and notify the Project Manager, the client, and the
Quality Assurance Coordinator in memorandum form.

13.2 Long-term Corrective Action

Long-term corrective action procedures are devised and implemented to
prevent the recurrence of a potentially serious problem. The Quality
Assurance Coordinator will be notified of the problem and will conduct an
investigation to determine the severity and extent of the problem. The
Quality Assurance Coordinator will then file a corrective action request
with the Project Manager and Quality Review Team. In case of dispute

between the Quality Review Team and the Project Manager, the Responsible Corporate Officer will make a final determination for the company.

Corrective actions may also be initiated as a result of other activities including:

o Performance Audits;
o System Audits;
o Laboratory/field comparison studies;
o Quality Assurance/Quality Control program audits conducted by the Quality Review Team.

The Quality Assurance Coordinator will be responsible for documenting all notifications, recommendations, and final decisions. The Project Manager and the Quality Assurance Coordinator will be jointly responsible for notifying program staff and implementing the agreed upon course of action. The Quality Assurance Coordinator will be responsible for verifying the efficiency of the implemented actions. The development and implementation of preventative and corrective actions will be timed, to the extent possible, to minimize any adverse impact on project schedules and subsequent data generation/processing activities. However, scheduling delays will not override the decision to correct the data collection deficiencies or inaccuracies before proceeding with additional data collection. The Quality Assurance Coordinator will also be responsible for developing and implementing routine program controls to minimize the need for corrective action.

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14.0 REPORTS TO MANAGEMENT

Periodic summary reports will be prepared to inform management of project status. The reports will include:

1. Periodic assessment of measurement data accuracy, precision, and completeness;

2. Results of performance audits and/or systems audits;

3. Significant Quality Assurance/Quality Control problems and recommended solutions;

4. Status of solutions to any problems previously identified.

Additionally, any incidents requiring corrective action will be fully . documented. Procedurally, the Quality Assurance Coordinator will prepare the reports to management. These reports will be addressed to the Project Manager and the Quality Review Team. The summary of findings shall be factual, concise, and complete. Any required supporting information will be appended to the report.

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  │  K. BRISSETTE   │   │   G. GORSKI     │
  │  P. ROMZICK     │   │                 │
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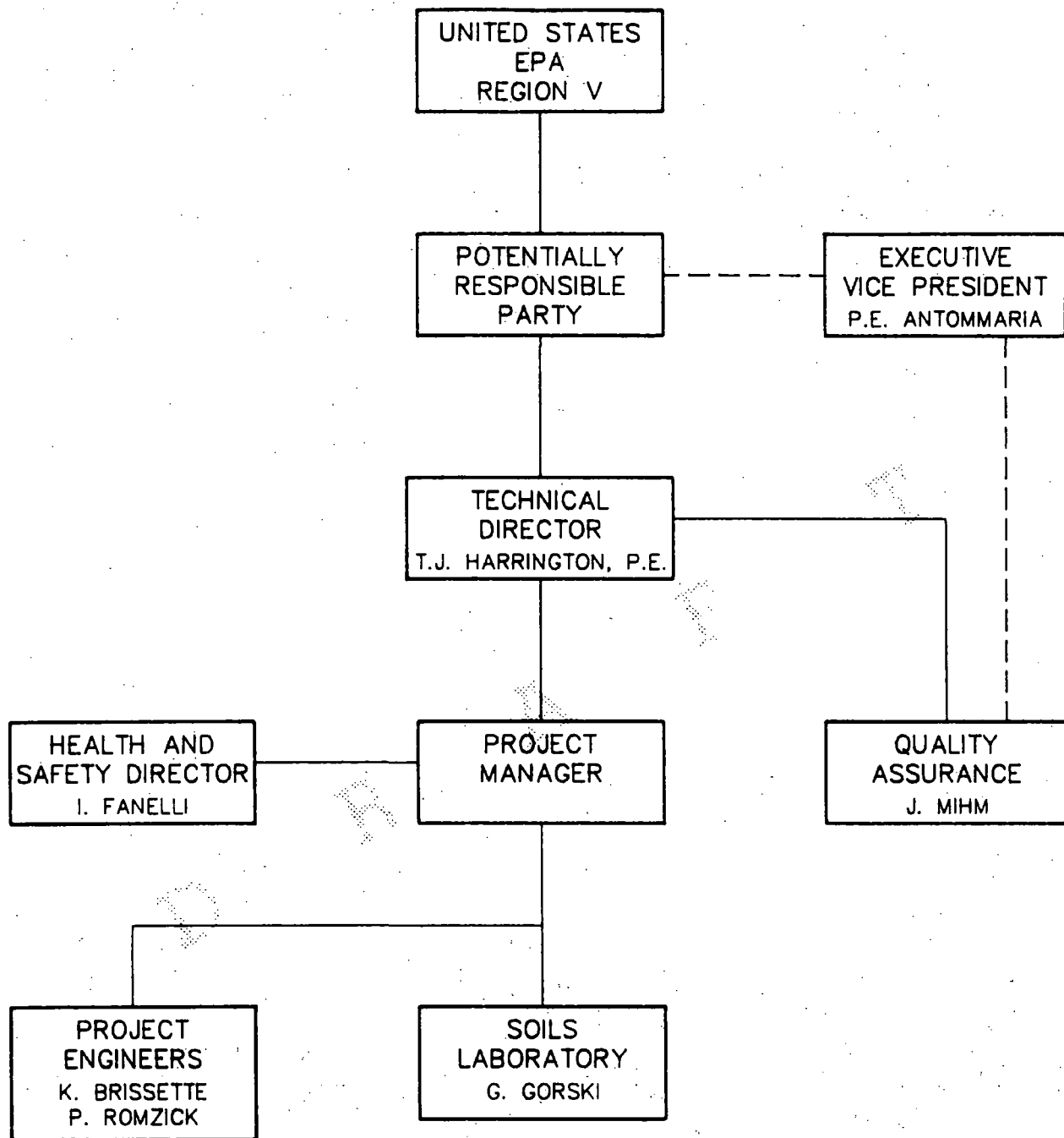
WORK PLAN
PROJECT MANAGEMENT TEAM
WAUKEGAN HARBOR SITE

FIGURE 1

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DEFINE DATA REQUIREMENT

DEFINE METHODOLOGY ⟶ IDENTIFY FIELD EQUIPMENT REQUIRED ⟶ CALIBRATION OF EQUIPMENT

DOCUMENT EQUIPMENT IDENTIFICATION ⟵ DOCUMENT CALIBRATION

VERIFY SAMPLE LOCATION

IDENTIFY SAMPLE TYPE

IDENTIFY Q.C. SAMPLES, IF NEEDED

SAMPLE COLLECTION ⟶ DUPLICATE SAMPLES IF REQUIRED ⟶ DOCUMENT DUPLICATE IDENTIFICATION

MEASUREMENT

CHECK CALIBRATION OF EQUIPMENT

DOCUMENT RE-CALIBRATION

FIELD REPORTING

DATA CONVERSION ⟶ VERIFICATION OF CALIBRATIONS ⟶ VERIFICATION

FINAL REPORT

DATA REVIEW

ACCEPTABLE DATA

FIELD DATA
COLLECTION AND VALIDATION
FIGURE 2

CanonieEnvironmental

2
Results of EP Toxicity metals Analysis on Soil
Samples Received From Fairchild, McKin
Results in mg/l leachate

01-09-19
84-130-1514
Page 4

Sampler ID:	A1-10	A1-12	A1-2	A1-3	A1-4
Lab ID#:	616611	616613	616603	616604	616605
Analyte(s)					
Arsenic	ND 0.5	ND 0.5	ND 0.5	ND 0.5	ND 0.5
Barium	ND 10.	ND 10.	ND 10.	ND 10.	ND 10.
Cadmium	ND 0.10	ND 0.10	ND 0.10	ND 0.10	ND 0.10
Chromium (Total)	ND 0.5	ND 0.5	ND 0.5	ND 0.5	ND 0.5
Mercury	ND 0.02	ND 0.02	ND 0.02	ND 0.02	ND 0.02
Lead	ND 0.5	ND 0.5	ND 0.5	ND 0.5	ND 0.5
Selenium	ND 0.1	ND 0.1	ND 0.1	ND 0.1	ND 0.1
Silver	ND 0.5	ND 0.5	ND 0.5	ND 0.5	ND 0.5

FIGURE 4

Note:
ND X denotes none detected to a level of X
#ND X denotes none detected to a level of X due to an interfering peak

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APPENDIX A

LABORATORY QUALITY ASSURANCE PROGRAM

CANONIE ENVIRONMENTAL
SERVICES CORPORATION

QUALITY ASSURANCE PROGRAM

Kenneth C. Wahl
Manager of Laboratory Services

Sharon K. Pierson
Quality Assurance Officer

September 1987

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1.0 INTRODUCTION

The purpose of the following Quality Assurance (QA) and Quality Control (QC)
program is to ensure that the data generated by Canonie Environmental Services
Corp., (Canonie) are accurate, precise, and, if necessary, will provide a
sound legal background for any enforcement activities.   The QA/QC program
utilized by Canonie is based on EPA and CLP criteria.

The QA program is designed to ensure the reliability in the identification and
measurement data.   The QC program is designed to obtain prescribed standards
of performance in the identification and measurement data. The above areas
will be discussed in detail along with sampling, collection and preservation,
sample control (log-in & storage), instrument calibration and maintenance, and
analytical methodology.

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2.0 LABORATORY PERSONNEL

The QA/QC program is not only the responsibility of the laboratory manager, organic and inorganic supervisors, and the QA officer, it is the responsibility of the entire Canonie Staff.

Canonie prides itself on the qualified personnel in its employ. As new personnel are hired, the same standards will apply. Personnel undergo a thorough and on-going training program, which includes going to seminars and training courses covering instrumentation, analytical methodology, and sampling techniques.

Weekly staff meetings are held to discuss new ideas, problems and their solution, and safety. Seminars are conducted periodically to allow everyone in the laboratory to become familiar in areas other than their expertise.

The laboratory staff at Canonie is made up of 30 experience chemist, biologist, and technical assistant. A brief review of Canonie's personnel is given. A more complete resume is available upon request.

Attachment I is the organizational chart for the laboratory. Each section has a section chief who is responsible for verifying all analytical work performed in that section. A quality assurance officer is responsible for the laboratory wide quality assurance program and directing corrective action as needed.

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RESUMES

CANONIE ENVIRONMENTAL SERVICES CORP.

Kenneth Wahl: Project Manager; M.S. and B.S. Chemistry, 15 years
laboratory experience in the toxicology and environmental
areas. Responsible for the overall daily operations of the
laboratory.

Jon Bartell: Project Supervisor; B.S. Biology/Chemistry, Masters Business
Administration, 17 years of laboratory experience.
Responsible for marketing analytical and engineering
services. Proficient in all areas of the laboratory with
varied sample types, including environmental and industrial
processes.

John Buerger: Project Supervisor; B.S. Chemistry/Biochemistry,
Laboratory Operations Manager, 4 years Environmental
Chemistry experience. Proficient in all areas of organic
analyses, and computer automated systems.

Jerry Martin: Project Scientist; GC/MS Supervisor; B.S. Environmental
Science, 11 years laboratory experience, with 6 years GC/MS
analysis and interpretation, including CLP samples and
associated documentation.

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Roy Sloan: Project Scientist; Inorganic Supervisor; B.S. Chemistry, 10 years laboratory and supervisory experience. Proficient in AAS, ICP, ion chromatography, and wet chemical analyses. Experienced in developing and maintaining inorganic quality assurance programs.

Sharon Pierson: Assistant Project Scientist; Quality Assurance Officer, B.S. Biology, 5 years laboratory experience, GC/MS Operator; 4 years in environmental laboratory. Experienced in GC purge and trap methods and Inorganic Chemistry. Also experienced in Worker Health and Safety, State and Federal Hazardous Waste Regulation.

Arlen Neckels: Assistant Project Scientist; GC/MS VOA Operator; 23 years laboratory experience, 5 years in environmental laboratory. Experienced in GC, HPLC, AA, U.V. Spectrophotometry, Flame Photometry and Colorimetry.

Michael Aseltine: Assistant Project Scientist; B.S. Biology, 4 1/2 years lab and field experience. Proficient in Gas Chromotagraph, specialty area in Volatile Organic Analysis.

Jack Shimasaki: Assistant Project Scientist; Inorganic Supervisor, A.B. Chemistry. Over 25 years of laboratory experience including analysis of agriculturally related products. Specialty in Inorganic Analysis.

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Jim Hoch: Assistant Project Scientist; Pesticide/Herbicide Specialist, B.S. Chemistry, 6 years research lab experience. Proficient in Capillary GC, HPLC, IR, UV, and FT-NMR.
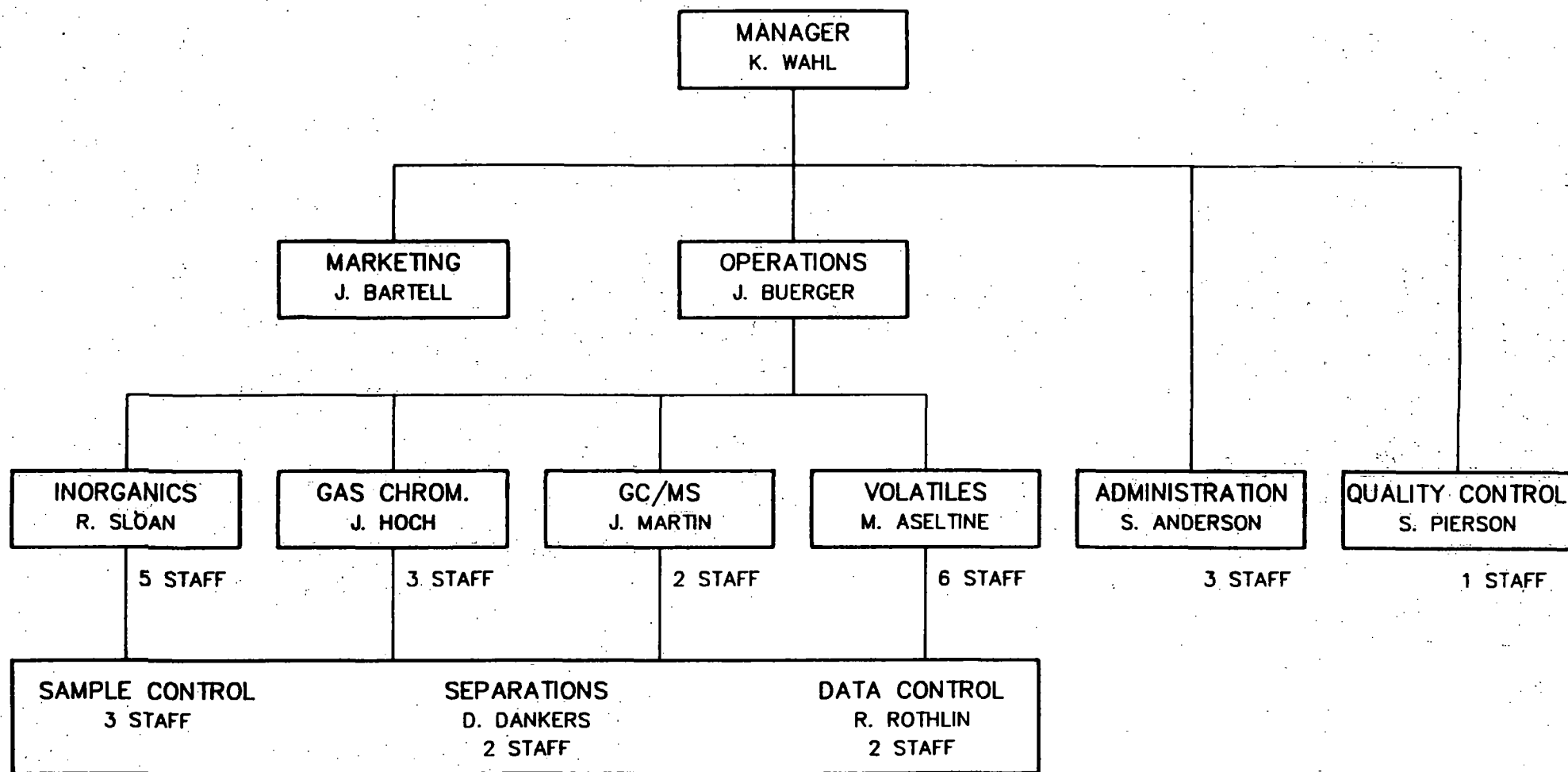
Donna Allsup: Chemist, Pesticide/Herbicide Specialist, B.S. Chemistry, Chemical Engineering (Drilling Fluids) 10 years laboratory experience, 5 years experience in marketing and management.

Dale Gimble: Chemist, Pesticide/Herbicide Specialist, B.S. Biochemistry, 4 years pesticide extraction experience, Gel Premeation Column experience, proficient in sample preparation and cleanup.

Gail Adams: Chemist; B.S. Forensic Sciences/Chemistry, 4 years Laboratory experience. Experienced in Volatile Organic Analysis and Inorganic Analysis. Proficient in all aspects of VOA analysis, start-up and operation of the purge and trap and GC system. Experienced in the operation of an AA.

Shakoora Azimi: Chemist; B.S. Chemistry and Biology, 3 years laboratory Experience in both inorganic preparation and all wet chemistry analysis. Proficient in all aspects of Volatile Organic Analysis and the operation of headspeace analyzers, purge and trap systems, and gas chromatographs.

Mark Traxler: Chemist; B.S. Biochemistry, 7 years experience in Analytical chemistry, including 3 years with Canonie. Proficient in ICP, GFAAS, AA, IC, UV-VIS and all other instruments involved in inorganic analysis of soils, waters and hazardous wastes.

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                        │     MANAGER      │
                        │     K. WAHL      │
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        │INORGANICS│ │GAS CHROM.│ │ GC/MS  │ │ VOLATILES │ │ S. ANDERSON  │ │  S. PIERSON  │
        │ R. SLOAN │ │ J. HOCH  │ │J.MARTIN│ │M. ASELTINE│ └──────────────┘ └──────────────┘
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        │ SAMPLE CONTROL     SEPARATIONS      DATA CONTROL      │
        │    3 STAFF         D. DANKERS        R. ROTHLIN       │
        │                     2 STAFF          2 STAFF          │
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ADMINISTRATIVE ORGANIZATION
STOCKTON LABORATORY
ATTACHMENT I
CanonieEnvironmental

3.0 SAMPLING PROCEDURES

One of the most important things to keep in mind is that the information obtained from the analysis of a sample is only as good as the sample itself. The sample should be as close a representative of the actual site in question as possible.

Canonie Environmental Services Corp. provides its own sampling service upon request, using techniques in accordance to EPA's "Characterization of Hazardous Waste Sites-A, Methods Manual: Volume II, Available Sampling Methods" and "Standard Methods".

After sampling, the chemical and physical integrity of the sample must be maintained. Preservation of the sample is dependent upon the sample type and the required analysis. Usually keeping the sample on ice and sending it to the laboratory as soon as possible after sampling is sufficient.

Table I lists the recommended sampling, preservation procedure, container, and sample volume.

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Parameter	Collection Technique	Container	Volume (ml)	Preservation	Holding Time	Method Technique	Method	Detection Limit
Acidity	Grab or Composite	P,G	100	Cool, 4 degrees C	14 days	Potentiometry	305.2	1.0
Alkalinity	Grab or Composite	P,G	100	Cool, 4 degrees C	14 days	Potentiometry	310.1	1.0
Ammonia	Grab or Composite	P,G	400	H2SO4 to pH <2	28 days	Spectrophotometry	SM 417B	0.1
BOD	Grab only	P,G	1000	Cool, 4 degrees, C	48 hours	Membrane Electracle	405.1	1.0
Bacteria	Grab only	P,G	200	Cool, 4 degrees C, 10% Na2S2O3, EDTA	6 hours	5 tube MPN	SM 908	2.2
Bicarbonate/Carbonate	Grab only	P,G	100	Determine onsite	No holding	Titrimetry	ASTM D513C	5.0
Boron	Grab or Composite	P,G	100	Cool, 4 degrees C	7 days	Spectrophotometry	ASTM 3082	0.1
Bromide	Grab or Composite	P,G	100	None required	28 days	Spectrophotometry	320.1	1.0
COD	Grab only	P,G	50	H2SO4 to pH <2; Cool 4 degrees C	28 days	Digestion	410	10.
Calorimetry	Grab or Composite	P,G	100	Cool, 4 degrees C		Parr Bomb		
Carbon dioxide	Grab only	P,G	100	Cool, 4 degrees C	24 hours	Titrimetry	ASTM D513C	1.0
Chloride	Grab or Composite	P,G	50	None required	28 days	Titrimetry	325.3	1.0
Color	Grab or Composite	P,G	50	Cool, 4 degrees C	48 hours	Visual Comparison	110.2	1.0
Conductance	Grab or Composite	P,G	100	Cool, 4 degrees C	28 days	Conductivity, Meter	120.1	
Corrosivity	Grab or Composite	G	1000	Cool, 4 degrees C		Corrosivity toward Steel	1110	

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Parameter	Collection Technique	Container	Volume (ml)	Preservation	Holding Time	Method Technique	Method	Detection Limit
Cyanide	Grab or Composite	P,G	500	NaOH to pH>12, 0.6g Ascorbic Acid	14 days	Distillation	9010	0.02
Fluoride	Grab or Composite	P	300	None Required	28 days	Specific Ion Electrode	340.2	0.1
Hardness	Grab or Composite	P,G	100	HNO3 to pH <2	6 months	Titrimetry	130.2	1.0
Hexavalent Chromium	Grab or Composite	P,G	100	Cool, 4 degrees C	24 hours	Spectrophotometry	SM 312.3	0.005
Hydroxide	Grab or Composite	P,G	100	Cool, 4 degrees C	14 days	Titrimetry	ASTM D 514	1.0
Ignitability (Flash Point)	Grab or Composite	G	200	Cool, 4 degrees C		Closed Cap	1010	
Metals Suspended (except Cr VI)	Grab or Composite	P,G	1000	Filter onsite	6 months, except Hg—28 days	Atomic Absorption	200.	See pg 57-59
Metals, Dissolved (except Cr VI)	Grab or Composite	P,G	1000	Filter onsite, HNO3 to pH <2	6 months, except Hg—28 days	Atomic Absorption	200.	See pg 57-59
Metals, Total (except Cr VI)	Grab or Composite	P,G	1000	HNO3 to pH <2	6 months, except Hg—28 days	Atomic Absorption	200.	See pg 57-59
Nitrate	Grab or Composite	P,G	100	Cool, 4 degrees C H2SO4 to pH < 2	48 hours 28 days	Spectrophotometry	353.3	0.05
Nitrite	Grab or Composite	P,G	50	Cool, 4 degrees C	48 hours	Spectrophotometry	354.1	0.005
Nitrogen, Kjeldahl (total)	Grab or Composite	P,G	500	HNO3 to pH <2	28 days	Distillation, Titrimetry	351.3	0.1
Odor	Grab only	G	200	Cool, 4 degrees C	24 hours	Sensory Detection	140.1	1.0
Oil & Grease	Grab only	G	1000	Cool 4 degrees C H2SO4 to pH <2	28 days	Extraction, Gravimetry	413.1	1.0
Organic Compounds	Grab only	G	3000	Cool, 4 degrees C	7 days	Gas Chromatography	600 series	See pg 27-52

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Table   .'t)

Parameter	Collection Technique	Container	Volume (ml)	Preservation	Holding Time	Method Technique	Method	Detection Limit
Organic Lead	Grab or Composite	G	1000	Cool, 4 degrees C		MIBX Extraction		
Oxygen (dissolved)	Grab only	G	300	None	Analyze Immediately	Membrane Electrode	360.1	0.1
Percent Moisture	Grab or Composite	P,G	50 gms	Cool, 4 degrees C		Oven drying		
pH	Grab only	P,G	25	None	Analyze Immediately	pH Meter	150.1	—
Phosphates, Ortho	Grab or Composite	P,G	50	Cool, 4 degrees C	48 hours	Spectrophotometry	365.2	0.01
Phosphorus, Total	Grab or Composite	P,G	50	H2SO4 to pH <2	28 days	Spectrophotometry	365.4	0.01
Salinity	Grab or Composite	P,G	500	Cool, 4 degrees C	28 days	Hydrometer	SM 210 B	
Silica	Grab or Composite	P	50	Cool, 4 degrees C	28 days	Spectrophotometry	370.1	0.05
Solids Total Dissolved	Grab or Composite	P,G	100	Cool, 4 degrees C	7 days	Gravimetry	160.1	1.0
Solids Total Settleable	Grab or Composite	P,G	1000	Cool, 4 degrees C	48 hours	Gravimetry	160.5	0.5
Solids Total	Grab or Composite	P,G	100	Cool, 4 degrees C	7 days	Gravimetry	160.3	1.0
Solids Total Suspended	Grab or Composite	P,G	100	Cool, 4 degrees C	7 days	Gravimetry	160.2	1.0
Specific Gravity	Grab only	P,G	100	None	28 days	Pycnometer	ASTM D1429	—
Sulfate	Grab or Composite	P,G	50	Cool, 4 degrees C	28 days	Nephelometry	375.4	1.0

Table (.t)

Parameter	Collection Technique	Container	Volume (ml)	Preservation	Holding Time	Method Technique	Method	Detection Limit
Sulfide	Grab or Composite	P,G	500	Cool, 4 degree C,2ml zinc acetate & NaOH	7 days	Titrimetry	376.1	1.0
Sulfite	Grab or Composite	P,G	50	Determine onsite	No holding	Titrimetry	377.1	2.0
Surfactants (MBAS)	Grab or Composite	P,G	250	Cool, 4 degrees C	48 hours	Extraction Spectrophotometry	425.1	0.05
Total Organic Carbon (TOC)	Grab or Composite	G, Teflon-lined cap	25	Cool, 4 degrees C HCl to pH <2	28 days	Combustion-Infrared	SM 505	1.0
Total Organic Halogens (TOX)	Grab or Composite	G, Amber Teflon-line	100	Cool, 4 degrees Cadd 1ml 0.1M Na sulfite	7 days	TOX Instrumentation		
Tannins & Lignins	Grab or Composite	P,G	100	None	48 hours	Spectrophotometry	SM 513	0.1
Turbidity	Grab or Composite	P,G	100	Cool, 4 degrees C	48 hours	Nephlometry	180.1	0.01
Volatile Organics	Grab only	G	120	Cool, 4 degrees C	14 days	Gas Chromatography	601 and 602	See pg 27-29

4.0 SAMPLE CUSTODY

To meet the time constraints of each project and provide quality laboratory data requires careful coordination of the various laboratory activities. The main factors to be considered are: sample tracking from collection to the final report, sample preparation, and sample analysis time.

By notifying the laboratory prior to sampling will guarantee that:

1. By giving the laboratory prior notification of the number of samples and the sample matrix, the laboratory can schedule the work load accordingly.

2. Enough sample is taken to complete all testing.

3. The appropriate sample containers are used.

A. Notification of Analysis

1. A laboratory project number is assigned to the work requested. The number of samples are indicated on the project form, along with the sample matrix and the tests to be performed. Any other pertinent information that may assist in the handling of the samples is also noted. (See Attachment II.)

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2. If sample containers are to be provided by Canonie, the bottle request section is filled out which indicates the number and type of container and where and when to send them. (See Attachment II.)

3. Along with the sample containers, a chain-of-custody form (Attachment III) and sample labels are included as a complete package.

B. Sampling

1. Collection and preservation of the sample in accordance to analysis protocol must be maintained.

2. All information on the sample label should be completed.

3. The sample origination should be noted so there is never any question regarding sample origin.

4. The chain-of-custody should reflect the identification of the sample to appear on the final report, this can be up to 20 characters per sample ID.

5. Any unusal observations noted or problems encountered during sampling should be noted on the chain-of-custody form.

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C. Sample Receipt

1. When samples arrive at Canonie Environmental Services Corp., the chain-of-custody form and the samples are removed from the shipping container. At this time, the sample custodian checks to ensure that all the samples listed on the chain-of-custody are present and in good condition. The condition of the samples are recorded on the custody form.

2. Each sample container is given a unique six-digit laboratory ID number. The first number of the ID indicates the year in which the sample was received, i.e., samples received in 1986 begin with the number 6.

3. The sample custodian will then check to see if a laboratory project number has been assigned and that the initial work request matches the chain-of-custody analysis request.

4. The samples are then logged-in via computer which generates the sample tracking sheets (see Attachment IV) and the accession page (see Attachment V).

5. After completing all of the above, the appropriate section chief receives the complete project folder which includes:

   a. A copy of the laboratory project work request form.

   b. The chain-of-custody.

   c. The sample tracking sheets.

CanonieEnvironmental

:anonio Er ...tal Analytical Laboratory

:llont:_____ cc:_____ Project ._____ LP #:_____

Billing Address:_____ _____ Quote #:_____
                 _____ _____ Cllont P. O. #:_____
                 _____ _____ Source:_____E,L_____

Phone Number:_____ _____ Date Sampled:_____

Computer Login Information					Turn Around Time							Charge $	
Date e'c'd	# of Samples	Matrix	Analysis Code	Analysis	Lab Sect.	Verbals Date Due	Init.	Lab Work Date Due	Init.	Report Out Date Due	Init.	Cost/ Sample	Total

Analysis Comments:_____
_____
_____
_____

Bottle Shipping Request						Sampling – Pickup Charge		Charge	Total

Date Needed:_____ Date Shipped:_____ Init.:_____ || Date Sampled:_____ Sampling Hours:_____
Shipping:_____ ||
Address:_____ || Init.:_____ Total Miles:_____
         _____ || Subtotal:

Attention :_____ ||

			Outside Laboratory Work				Cost/	Total

Phone Number:_____ || Lab | Analysis | # Samples | Matrix | Date | Init. | Sample |
Ship Via:_____ ||

Container type	#	Container type	#		

Comments:_____

						Miscellaneous Charge		Charge	Total

Comments:_____

GRAND TOTAL :_____

DATE	SAMPLE I.D.	NO. OF CON-TAINERS	ANALYSIS													REMARKS

PROJ. NO. **PROJECT NAME**

L.P. NO. **SAMPLERS: (Signature)**

Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Remarks
Relinquished by: (Signature)	Date/Time	Received by: (Signature)	
Relinquished by: (Signature)	Date/Time	Received for Laboratory by: (Signature)	

Canonie Environmental, 212 Frank West Circle, Suite A, Stockton, CA 95206

Nº

White Sampler   Canary Return Copy To Shipper   Pink Lab Copy   Attachment III

☐ CANONIE ENVIRONMENTAL LABORATORY SAMPLE TRACKING SHEET			LP #:		

CLIENT:
PROJECT #:

ANALYSIS:
MAT

DA LED:
DA IVED:
COST

COMMENTS:

			SAMPLER I.D.		LAB. I.D.	CONTAINER
SAMPLE VOL/WGT:		FINAL EXTRACT VOL:	COLUMN			
	LINE 1	LINE 2	DATE			
SAMPLE I.D.:			DILUTION			
LAB I.D.:		DATE PREP'D:	WORKER			
UNITS:		DATE ANAL:	LAB I.D.			
MDL	ANALYTE(S)		FINAL			

Attachment IV

CanonieEnvironmental

ACCESSION LOG BOOK

87-19

RECEIVED FROM	DATE RECEIVED RECEIVER	COMMENTS ANALYZED	DISPOSED	LABEL	LAB. NUMBER

Attachment V

Canonie Environmental

LABORATORY SAMPLE NUMBER	ACCESSION BY:	DATE AND TIME REMOVED	*REASON	DATE AND TIME RETURNED

*REASON CODE
1 = INITIAL STORAGE   2 = SAMPLE PREPARATION   3 = SAMPLE ANALYSIS   4 = DISPOSAL   5 = OTHER (INCLUDE BRIEF STATEMENT)

Attachment VI

6. The samples are then placed in a refrigerator and maintained at 4°C, unless immediate analysis or preservation is required. Should the samples require any special preservation, the custodian contacts the appropriate chemist in order to properly preserve the samples. The preservation performed on the samples is noted on the chain-of-custody form.

7. The sample custodian is responsible for the removal of all samples from storage and for indicating the date they were removed in the sarple control book (See Attachment VI).

D. Initiation of Analysis.

The Section Chief reviews the paperwork for accuracy and completeness then divides the work up according to analysis type. Each chemist is responsible for ensuring that samples are extracted according to analysis protocol and in a timely fashion to complete the work by the project due date.

5.0 CALIBRATION AND MAINTENANCE PROCEDURES

To assure the performance of the instruments used by Canonie Environmental
Services Corp., records are kept on any maintenance done, both preventative
and necessary. The record contains the date, worker, problems (if any),
maintenance performed, and the results.

1. Gas and Liquid Chromatographs

    The chromatographs are calibrated daily for each analysis
    to be performed. Calibration is done upon initial start-up
    and is rechecked periodically during the day depending on
    the number of samples run through the instrument. Calibration
    is done using a standard in the middle of the linear range for
    the instrument. As a general rule, after 10 samples are
    analyzed, the calibration curve is checked. Between
    calibrations, a QC sample is also monitored.

    Initial calibration of the instrument is based on a five-point
    curve. Once linearity has been demonstrated, a three-point
    curve is routinely analyzed. From the initial calibration, an
    average response factor (conc./area) is determined from the
    five points. This response factor is compared to the response
    factor generated from the daily calibration. The daily
    response factor should be within $\pm$ 10% of the average response
    factor; if it lies outside these limits a three-point curve is
    performed. If linearity is not acheived, then actions are
    taken to rectify the situation. Depending on the particular
    instrument and detector, a variety of routine maintenance is
    required.

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2. GC/MS Calibration

Each GC/MS system must have the hardware tuned to meet the criteria listed in Exhibit E for a 50 ng injection of decafluorotriphenyl phosphine (DFTPP), for bromoflurobenzene (BFB). No sample analyses can begin until all these criteria are met. this criteria must be demonstrated each 12 hour shift. DEFTPP or BFB has to be injected to meet this criterion. Post-acquisition manipulation of abundances is not acceptable.

3. Atomic Absorption Spectrophotometer

The atomic absorption spectrophotometer is calibrated using a minimum of 3 standards and a blank for each parameter to be analyzed. After 10 samples have been tested, the intermediate standard is rechecked. As long as the value for the intermediate standard is within $\pm$ 10% of the known value, analysis continues. If the instrument has drifted, it is recalibrated using 3 standards and the samples previously analyzed are checked against the new calibration curve.

For each analyte tested by atomic absorption spectrophotometer, the response factor (conc./abs.) for high and low levels are monitored. If the response factors deviate from the typical factors recorded, then a fresh standard is used. The physical adjustments are also checked, along with the lamp, and, in the case of graphite work, a new tube is put into operations. If this does not bring the response factor in line with those previously recorded, then maintenance is required.

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4. Inductively Coupled Plasma Spectrometer

Calibration

Six solutions are used to calibrate and to verify the
calibration of the ICP. These are (1) calibration blank
solution (2) calibration standard solution, (3) initial
calibration verification standard solution (4) interference
check standard solution (5) linear check standard solution and
(6) a quality control standard solution. The analytical curve
is generated by the calibration blank and the calibration
standard solution. After generation of the analytical curve,
the initial calibration verification standard solution is
analyzed. The recovery must be 90 to 110% of the expected
value. The interference check standard is analyzed next. The
recovery must be within a 40% window (80 to 120%). The linear
check standard is then analyzed. The value of this standard is
at two times the detection limit. Next a quality control
standard is analyzed. The standard is usual from an outside
source (EPA and/or ERA). The recovery of the standard must be
within 90 to 110% of the expected value. If any of the above
given criteria for any standard fails the problem must be
corrected and the instrument recalibrated.

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5. Analytical Balances

Daily or with each use, whichever is less frequent, a single class S-weight, near the typical weighing range, is weighed and recorded in a bound notebook. Should the weight deviate from the true value by 0.5%, the balance is inspected and checked to see that the pan is clear of any obstructions. The weight is checked on a different balance to verify if the S-weight is in error. If the weight passes the check, the balance must be inspected by a certified technician. Annually, the balances at Canonie Environmental Services Corp. are inspected and certified as to their accuracy.

6. Refrigerators

Since most of the samples received by the laboratory have required temperatures for preservation, it is imperative that the true operating temperature be known. Therefore, the daily temperature of the refrigerators are recorded in bound notebooks. Should the refrigerators not meet the required temperatures, corrective measures are taken.

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7. Ovens

A daily temperature check is performed on ovens used for TSS
and TDS analysis. Ovens not used for analysis purposes are
monitored every 6 months to insure that the temperature range
is accurate.

8. Thermometers

All thermometers used by Canonie Environmental Services Corp.
are calibrated against an NBS certified thermometer. Each
thermometer has a unique identification tag in order to monitor
its performance. Annually, the thermometers are checked for
their accuracy by submerging them in three different
temperature baths. Thermometers found to deviate more than $1^{\circ}C$
for a given range are used for noncritical work, or discarded.

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9. pH Meters

Before using the pH meter, the probe is carefully examined for any physical damage. The pH meter is calibrated on a pH 7.0 buffer solution and a pH 4.0 or pH 10.0, depending on the range to be monitored. A log book is maintained for the pH meter.

10. Conductivity Meter

Before using the meter, closely inspect the condition of the electrode for any physical wear or damage. If the coating appears damaged, then the electrode should be replatinized according to manufacturer's guidelines.

Periodically, the conductivity cell is checked over a range of at least 5 concentrations of KCl listed in table 205.1 of the 16th edition of Standard Methods.

11. Turbidimeter

Daily or with each use, whichever is less frequent, a 4 NTU and a 40 NTU formazin standards are measured and recorded. Periodically, the turbidimeter is calibrated according to the method described in Standard Methods, 16th edition, Section 214 a.

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12. Repeating Pipets

Before delivering precise volumes, the pipets are checked for their accuracy by weighing water dispensed by five fill-and-dispense cycles. Based on the weight of the pure water, the mean dispensed volume can be determined for the pipet.

13. Glassware

Before using any glassware, check for any damage such as stars, cracks, or scratches. Laboratory glassware must be kept scrupulously clean to assure that there will be no contamination of samples or sample extracts. Depending on the eventual use of the glassware, several different cleaning methods are incorporated.

a. Volatile Organic Analysis (VOA)

Glassware used in VOA analysis are soaked in a tub of a cleaning solution containing no chlorines (Palmolive soap works well). The glassware is then washed in a sink using a fresh portion of the same detergent, then rinsed, first with tap water and then with organic pure water. The glassware is then transferred in to an oven and baked to ensure all volatile compounds are removed.

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b. Organic Analysis

The glassware is first soaked in a dilute solution of Palmolive soap, rinsed, and then washed in a fresh soap solution. Next, a rinsing with tap water, followed by deionized water is performed. The glassware is placed on a drying rack until dry. They are then rinsed with acetone, allowed to dry, the exposed ends are wrapped with tin foil, and then put away for future use.

c. Inorganic Analysis

The glassware is first rinsed with a 1% solution of nitric acid. Next, they are washed using a phosphorous free detergent (Alconox), and rinsed once using tap water. The glassware is then rinsed using deionized water, followed by a 1% solution of nitric acid, and again with deionized water. They are then inverted on a rack until dry, and put in their proper storage area.

14. All Other Equipment

All other equipment is checked quarterly as to its general condition and for any physical damage. If any problems are noted, corrective actions are taken.

15. Instrument Log Book

All major instrumentation used at Canonie have an analysis log book. For every day that analysis is performed on the instrument, the log book is filled in with the sample analysis list. This includes blanks, calibration standard, QC work, and the sample ID's.

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B. Preparation of Parent Solutions

When making up the parent solutions, a log book is maintained
to record all the necessary information. A code number (prefixed
with a "P") is assigned to the parent solution, the date it was
made, analyst, code numbers of the standard and reagent used, all
weights and volumes used are recorded on the Parent Solution
Preparation Log. (See Attachment VIII). A balance check is also
performed at the same time. All parent solution bottles are
labeled with the code number, exact contents, date made, solvent,
analyst, expiration date, and a mark on the side of the label to
indicate the solvent line. Each time a significant aliquot is
removed, a new mark is placed on the label. This is done in order
to determine if evaporation has occurred.

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C. Preparation of Stock Standards and Quality Control Stock

All compounds used in the preparation of stock standards or
quality control stock by the laboratory are of a certified
purity by the manufacturer.

A log book is maintained when preparing a stock solution. The date
prepared, analyst, code numbers of all standards or parent
solutions used, amounts added, final volume, solvent code number,
etc. are entered into the log book. (See Attachment IX).

Commerically certified stock mixtures are also utilized by Canonie
Environmental Services Corp. These stock mixtures are checked by
analyzing quality assurance test samples obtained for the EPA or
ERA.

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D. General Storage

Proper storage of reference standards is an essential part of the analytical process.

When a container is removed from storage, it should be allowed to come to room temperature before opening. The bottle cap should remain off only long enough to withdraw the amount needed. After use, the bottle should be returned to storage immediately.

1. Purified Undiluted Standards

Place purified standards in a container, preferably with desiccant, and stored in an explosion proof refrigerator.

2. Concentrated "Stock" Solutions

a. Stored at approximately 4°C.

b. Replace stable compounds such as organochlorines and triazines after six months or when degradation is apparent.

c. Replace compounds that degrade only at ambient temperatures after six months or when degradation is apparent.

d. Monthly replacement for unstable compounds such as butylate, CDED, and disulfoton.

e. Degradation studies are performed on DDT and Endrin in accordance to CLP protocol.

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3. Dilute "Working" Solutions

    a. Store stable compounds in a refrigerator if not in daily use and reprepare by dilution of "stock" solution periodically. Replace sooner if solvent evaporation is evident.

    b. Stable solutions kept on lab benches should be replaced with fresh dilutions of "stock" after three months or with unopened standards from refrigerator storage. Replace sooner if solvent loss is evident.

    c. Compounds known to be unstable at ambient temperatures should be stored in a refrigerator between uses and replaced with fresh "stock" dilutions every two months. Replace sooner if solvent loss is evident.

    d. Unstable compounds should be stored in a refrigerator between used and replaced with fresh "stock" dilutions every week.

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E. Solvent Monitoring

Solvents used for Organic analysis are checked for their purity by concentrating 200 mls to 1 ml and injecting it onto the instrument. Solvents showing interferences are not used for the analysis.

F. Deionized Water

Deionized water is produced on the premises. The resistivity is checked and recorded each time water is produced. Every three months the following tests are performed on the deionized water: pH, conductivity, silica content, total solids, and total organic carbon. The results from these tests are kept in a log book.

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CODE NUMBER	ITEM	DATE RECEIVED	MANUFACTURER, LOT No., CONCENTRATION	EXPIRATION DATE	COMMENTS
					Attachment VII

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STANDARD PREPARATION LOG

STOCK CODE No.	DATE PREP.	WORKER SIGNATURE	CODE No. AND NAME OF STANDARD	PURITY	FINAL WT. TARE WT. NET WT. (GRAMS)	ADJUSTED NET WT. (GRAMS)	SOLVENT NAME AND CODE No.	DILUTION VOLUME (ml)	FINAL CONC. (ml)	OBSERVER SIGNATURE
										Attachment VIII

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PREPARATION AND STANDARDS TRACKING SHEET

PREPARATION OR STANDARD CODE	PREP. DATE	STANDARDS CODES	VOLUME USED	VOLUME PREPARED	REAGENT AND CODE	PREPARED BY	STANDARDIZED BY / DATE	ACTUAL CONCENTRATION	UNITS	RESTAND. OR EXP. DATE	COMMENTS

Attachment IX

6.0 ANALYTICAL PROCEDURES

Canonie Environmental Services Corp. uses only analytical methods and procedures that are approved by the USEPA, or other agency to which the customer is responsible.

Most procedures utilized come directly from EPA/4-79-020 EPA "Methods for Chemical Analysis of Water and Wastewater," EPA SW-846 "Test Methods for Evaluating Solid Waste," and "Standard Methods for the Examination Water and Wastewater, 16th edition, 1985."

The following tables list the more common methods utilized for water and soils, along with the typical detection limits reported by Canonie:

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Table II
Purgeable Halocarbons

Analytes	Detection Limits Water (mg/1)	Soil (mg/kg)
Bromodichloromethane	0.0005	0.02
Bromoform	0.0005	0.02
Bromomethane	0.0005	0.02
Carbon tetrachloride	0.0005	0.02
Chlorobenzene	0.0005	0.02
Chloroethane	0.0005	0.02
2-Chloroethylvinyl ether	0.0005	0.02
Chloroform	0.0005	0.02
Chloromethane	0.0005	0.02
Dibromochloromethane	0.0005	0.02
1,2-Dichlorobenzene	0.0005	0.02
1,3-Dichlorobenzene	0.0005	0.02
1,4-Dichlorobenzene	0.0005	0.02
Dichlorodifluoromethane	0.0005	0.02
1,1-Dichloroethane	0.0005	0.02
1,2-Dichloroethane	0.0005	0.02
1,1-Dichloroethene	0.0005	0.02
trans-1,2-Dichloroethene	0.0005	0.02
1,2-Dichloropropane	0.0005	0.02
cis-1,3-Dichloropropene	0.0005	0.02
trans-1,3-Dichloropropene	0.0005	0.02
1,1,2,2-Tetrachloroethane	0.0005	0.02
Tetrachloroethene	0.0005	0.02
1,1,1-Trichloroethane	0.0005	0.02
1,1,2-Trichloroethane	0.0005	0.02
Trichloroethene	0.0005	0.02
Trichlorofluoromethane	0.0005	0.02
Vinyl chloride	0.0005	0.02
Methylene chloride	0.0005	0.02

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Table II
Purgeable Halocarbons

Other analytes available upon request
Freon
cis-1,2-Dichloroethene
EDB

Water
Analysis: Method 601
Sampling container: Specially prepared 40 ml volatiles vials, taken in triplicate.
Reference: Method for Organic Chemical Analysis of Municipal and Industrial Wastewater, PB83-201798, Method 601, U. S. Environmental Protection Agency, Cincinnati, Ohio, July 1982.

Soil
Analysis: Method 8010
Sampling Container: Air tight completely full brass tube, or 40 ml vial
Reference: Test Method for Evaluating Solid Waste, Physical/Chemical Methods.
SW-846, Method 8010, U. S. Environmental Protection Agency, 1982.

Shipping requirements: Packed in an iced cooler, with chain-of-custody.
Acceptable holding time to analysis: 14 days.
Method of analysis: Gas Chromatography.

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Table II
Purgeable Aromatics

Analytes	Detection Limits Water (mg/l)	Soil (mg/kg)
Benzene	0.005	0.2
Chlorobenzene	0.005	0.2
1,2-Dichlorobenzene	0.005	0.2
1,3-Dichlorobenzene	0.005	0.2
1,4-Dichlorobenzene	0.005	0.2
Ethylbenzene	0.005	0.2
Toluene	0.005	0.2
Xylene	0.005	0.2

Other analytes available upon request
Acetone
Isopropyl Alcohol
Other Volatile Hydrocarbons (PID detector)
Other Volatile Hydrocarbons (FID detector)

Water
Analysis: Method 602
Sampling container: Specially prepared acidified 40 ml volatiles vials,
taken in triplicate.
Reference: Methods for Organic Chemical Analysis of Municipal and Industrial
Wastewater, PB83-201798, Method 602 and 624, U. S. Environmental Protection
Agency, Cincinnati, OH, July 1982.

Soil
Analysis: Method 8020
Sampling container: Air tight completely full brass tube, or 40 ml vial
Reference: Test Methods for Evaluating Solid Waste, Physical/Chemical
Methods, SW-846, Method 8020, U. S. Environmental Protection Agency, 1982.

Shipping requirements: Packed in an iced cooler, with chain-of-custody.
Acceptable holding time to analysis: 14 days.
Method of analysis: Gas Chromatography

CanonieEnvironmental

Table II
Phenols

Analytes	Detection Limits	
	Water (mg/1)	Soil (mg/kg)
4-Chloro-3-methylphenol	0.001	10.
2-Chlorophenol	0.008	10.
2,4-Dichlorophenol	0.008	10.
2,4-Dimethylphenol	0.008	10.
2,4-Dinitrophenol	0.005	10.
2-Methyl-4,6-dinitrophenol	0.003	10.
2-Nitrophenol	0.005	10.
4-Nitrophenol	0.005	10.
Pentachlorophenol	0.005	10.
Phenol	0.008	10.
2,4,6-Trichlorophenol	0.001	10.

Other analytes available upon request
Tetrachlorophenol

Water
Analysis: Method 604
Sampling container: Specially prepared one liter bottle, taken in triplicate.
References: Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater, PB83-201798, Method 604, U. S. Environmental Protection Agency, Cincinnati, OH, July 1982.
Varian Liquid Chromatography Procedure #96, Determination of Trace Levels of Phenols in Water, Varian Instruments, Walnut Creek, California.

Soil
Analysis: Method 8040
Sampling container: Specially prepared mason jar or brass tube (200 g. required).
References: Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Method 8040, U. S. Environmental Protection Agency, 1982.
Varian Liquid Chromatography Procedure #96, Determination of Trace Levels of Phenols in Water, Varian Instruments, Walnut Creek, California.

CanonieEnvironmental

Table II
Phenols

Shipping requirements: Packed in an iced cooler, with chain-of-custody.
Samples are extracted within 7 days and completely analyzed within 30 days of collection.
Method of analysis: Liquid and Gas Chromatography.

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Table II
Organochlorine Pesticides

Analyte	Detection Limits	
	Water (ug/l)	Soil (mg/kg)
Aldrin	0.05	0.01
Alpha-BHC	0.05	0.01
Beta-BHC	0.05	0.01
Delta-BHC	0.05	0.01
Gamma-BHC	0.05	0.01
Chlordane	0.5	0.05
4,4'-DDD	0.05	0.01
4,4'-DDE	0.05	0.01
4,4'-DDT	0.05	0.01
Dieldrin	0.05	0.01
Endosulfan I	0.05	0.01
Endosulfan II	0.05	0.01
Endosulfan sulfate	0.05	0.01
Endrin	0.05	0.01
Endrin aldehyde	0.05	0.01
Heptachlor	0.05	0.01
Heptachlor epoxide	0.05	0.01
Toxaphene	5.	0.5
PCB-1016	0.5	0.01
PCB-1221	0.5	0.01
PCB-1232	0.5	0.01
PCB-1242	0.5	0.01
PCB-1248	0.5	0.01
PCB-1254	0.5	0.01
PCB-1260	0.5	0.01

Other analytes available upon request
DBCP
Methoxychlor

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Table II
Organochlorine Pesticides

Water
Analysis: Method 608
Sampling container: Specially prepared one liter sample bottles, taken in triplicate.
Reference: Method for Organic Chemical Analysis of Municipal and Industrial Wastewater, PB 83-201796, Method 608, U. S. Environmental Protection Agency, Cincinnati, OH, July 1982.

Soil
Analysis: Method 8080
Sampling container: Specially prepared mason jar or brass tube (200 g soil required).
Reference: Test Method for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Method 8080, U. S. Environmental Protection Agency, 1982.

Shipping requirements: Packed in an iced cooler, with chain-of-custody.
Samples are extracted within 7 days and completely analyzed within 30 days of collection.
Method of analysis: Gas Chromatography.

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Table II
PCB's (Polychlorinated Biphenyls)

Analytes	Detection Limits	
	Water (ug/l)	Soil (mg/kg)
PCB-1016	0.5	0.05
PCB-1221	0.5	0.05
PCB-1232	0.5	0.05
PCB-1242	0.5	0.05
PCB-1248	0.5	0.05
PCB-1254	0.5	0.05
PCB-1260	0.5	0.05

Water
Analysis: Method 608.3
Sampling container: Specially prepared one liter sample bottles, taken in triplicate.
Reference: Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater, PB83-201796, Method 608, U. S. Environmental Protection Agency, Cincinnati, OH, 1982.

Soil
Analysis: Method 8080.3
Sampling container: Specially prepared mason jar or brass tube (200 g soil required).
Reference: Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Method 8080, U. S. Environmental Protection Agency, 1982.

Shipping requirements: Packed in an iced cooler, with chain-of-custody. Samples are extracted within 7 days and completely analyzed within 30 days of collection.
Method of analysis: Gas Chromatography.

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Table II
PCB'S in Oil

Analytes	Detection Limits Oil (mg/kg)
PCB-1016	5.
PCB-1221	5.
PCB-1232	5.
PCB-1242	5.
PCB-1248	5.
PCB-1254	5.
PCB-1260	5.

Oil
Analysis: Method PCB Oil
Sampling container: Two 20-40 ml Vials, teflon or foil lined cap (provide at-least 15 ml volume).
Reference: EPA Test Method for the Determination of Polychlorinated Biphenyls in Transformer Fluid and Waste Oils, EPA-600/4-81-045, U. S. Environmental Protection Agency, Cincinnati, OH, September 1982.
Shipping requirements: Securely packed in a leak proof container with chain-of- custody.

Acceptable holding time to analysis: 28 days.
Method of analysis: Gas Chromatography.

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Table II
Polynuclear Aromatic Hydrocarbons

Analytes	Detection Limits	
	Water (mg/1)	Soil (mg/kg)
Acenaphthene	0.01	1.
Acenaphthylene	0.01	1.
Anthracene	0.01	1.
Benzo (a) anthracene	0.01	1.
Benzo (a) pyrene	0.01	1.
Benzo (b) fluoranthene	0.01	1.
Benzo (g,h,i) perylene	0.01	1.
Benzo (k) fluoranthene	0.01	1.
Chrysene	0.01	1.
Dibenzo (a,h) anthracene	0.01	1.
Fluoranthene	0.01	1.
Fluorene	0.01	1.
Indeno (1,2,3-cd) pyrene	0.01	1.
Naphthalene	0.01	1.
Phenanthrene	0.01	1.
Pyrene	0.01	1.

Water
Analysis: Method 610
Sampling container: Specially prepared one liter sample bottles, taken in triplicate.
Reference: Method for Organic Chemical Analysis of Municipal and Industrial Wastewater, PB 83-201798, Method 610, U. S. Environmental Protection Agency, Cincinnati, OH, July 1982.

Soil
Analysis: Method 8100
Sampling container: Specially prepared mason jar or brass tube (200 g soil required).
Reference: Test Method for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Method 8100, U. S. Environmental Protection Agency, 1982.

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Table II
Polynuclear Aromatic Hydrocarbons

Shipping requirements: Packed in an iced cooler, with chain-of-custody. Samples are extracted within 7 days and completely analyzed within 30 days of collection.
Method of analysis: Gas and Liquid Chromatography.

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Table II
Chlorinated Hydrocarbons

Analytes	Detection Limits	
	Water (mg/l)	Soil (mg/kg)
2-Chloronaphthalene	0.001	0.1
1,2-Dichlorobenzene	0.0015	0.15
1,3-Dichlorobenzene	0.0015	0.15
1,4-Dichlorobenzene	0.0015	0.15
Hexachlorobenzene	0.0005	0.1
Hexachloroethane	0.0005	0.1
1,2,4-Trichlorobenzene	0.0005	0.1
Hexachlorocyclopentadiene	0.001	0.1
Hexachlorobutadiene	0.001	0.1

Water
Analysis: Method 612
Sampling container: Specially prepared one liter sample bottles, taken in triplicate.
Reference: Method for Organic Chemical Analysis of Municipal and Industrial Wastewater, PB 83-201798, Method 612, U. S. Environmental Protection Agency, Cincinnati, OH, July 1982.
Soil
Analysis: Method 8120
Sampling container: Specially prepared mason jar or brass tube (200 g soil required).
Reference: Test Method for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Method 8120, U. S. Environmental Protection Agency, 1982.

Shipping requirements: Packed in an iced cooler, with chain-of-custody. Samples are extracted within 7 days and completely analyzed within 30 days of collection.
Method of analysis: Gas Chromatography.

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Table II
Chlorinated Herbicides

Analytes	Detection Limits Water (mg/l)	Soil (mg/kg)
2,4-D	0.02	0.02
2,4,5-TP	0.02	0.02

Other analytes available upon request
2,4,5-T
Dinoseb

Water
Analysis: Method 615
Sampling container: Specially prepared one liter sample bottles (amber), taken in triplicate.
Reference: Determination of Chlorinated Herbicides in Industrial and Municipal Wastewater, EPA-600/4-82-005, Method 615, EMSL, U. S. Environmental Protection Agency, Cincinnati, OH, July 1982.
Varian Liquid Chromatography Procedure #88, Reverse Phase Separation of 2,4-D and Silvex in Waste Water, Varian Instruments, Walnut Creek, California.

Soil
Analysis: Method 8150
Sampling container: Specially prepared mason jar or brass tube (200 g soil required).
Reference: Test Method for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Method 8150, U. S. Environmental Protection Agency, 1982.
Varian Liquid Chromatography Procedure #88, Reverse Phase Separation of 2,4-D and Silvex in Waste Water, Varian Instruments, Walnut Creek, California.

Shipping requirements: Packed in an iced cooler, with chain-of-custody.
Samples are extracted within 7 days and completely analyzed within 30 days of collection.
Method of analysis: Gas and Liquid Chromatography.

CanonieEnvironmental

Table II
Organophosphorus Pesticide

Analytes	Detection Limits Water (ug/l)	Soil (mg/kg)
DEF	1.	1.
Delnav	1.	1.
Diazinon	1.	1.
Dimethoate	1.	1.
Disulfoton	1.	1.
Ethion	1.	1.
Ethyl parathion	1.	1.
Malathion	1.	1.
Methyl parathion	1.	1.
Methyl trithion	1.	1.
Phorate	1.	1.

Water
Analysis: Method 622
Sampling container: Specially prepared one liter sample bottles, taken in triplicate.
Reference: Determination of Organophosphorus Pesticides in Industrial and Municipal Wastewater, EPA-600/4-82-008, Method 622, EMSL, U. S. Environmental Protection Agency, Cincinnati, OH, July 1982.

Soil
Analysis: Method 8140
Sampling container: Specially prepared mason jar or brass tube (200 g soil required).
Reference: Test Method for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Method 8140, U. S. Environmental Protection Agency, 1982.
Shipping requirements: Packed in an iced cooler, with chain-of-custody.
Samples are extracted within 7 days and completely analyzed within 14 days of collection.
Method of analysis: Gas Chromatography.

CanonieEnvironmental

Table II
Volatile Organics (GC/MS)

Analytes	Detection Limits	
	Water (mg/1)(1)	Soil (mg/kg)(2)
Benzene	0.005	0.125
Bromodichloromethane	0.005	C.125
Bromoform	0.005	0.125
Bromomethane	0.010	0.250
Carbon tetrachloride	0.005	C.125
Chlorobenzene	0.005	0.125
Chloroethane	0.010	0.250
2-Chloroethylvinyl ether	0.010	0.250
Chloroform	0.005	0.125
Chloromethane	0.010	0.250
Dibromochloromethane	0.005	0.125
1,2-Dichlorobenzene	0.005	0.125
1,3-Dichlorobenzene	0.005	0.125
1,4-Dichlorobenzene	0.005	0.125
Dichlorodifluoromethane	0.005	0.125
1,1-Dichloroethane	0.005	0.125
1,2-Dichloroethane	0.005	0.125
1,1-Dichloroethene	0.005	0.125
trans-1,2-Dichloroethene	0.005	0.125
1,2-dichloropropane	0.005	0.125
cis-1,3-Dichloropropene	0.005	0.125
trans-1,3-Dichloropropene	0.005	0.125
Ethylbenzene	0.005	0.125
Methylene chloride	0.005	0.125
1,1,2,2-Tetrachloroethane	0.005	0.125
Tetrachloroethene	0.005	0.125
Toluene	0.005	0.125
1,1,1-Trichloroethane	0.005	0.125
1,1,2-trichloroethane	0.005	0.125
Trichloroethene	0.005	0.125
Trichlorofluoromethane	0.005	0.125
Vinyl chloride	0.010	0.250

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Table II
Volatile Organics (GC/MS)

Other analytes available upon request

Secondary Quantitation List (optional at extra charge), analytes and detection limits subject to change.

Analytes	Detection Limits	
	Water (mg/l) (1)	Soil (mg.kg)(2)
Freon 113	0.005	0.125
Acetone	0.005	0.125
Isopropyl Alcohol	0.005	0.125
Ethylene Dibromide (EDB)	0.005	0.125

Water
Analysis: Method 624
Sampling container: Specially prepared 40 ml volatile vial, taken in triplicate.
Reference: Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater, PB83-201798, Method 624, U.S. Environmental Protection Agency, Cincinnati, OH, July 1982

Soil
Analysis: Method 8240
Sampling container: Air tight completely full brass tube.
Reference: Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Mehtod 8240, U.S. Environmental Protection Agency, 1982.

Shipping requirements: Packed in an iced cooler with chain-of-custody.
Acceptable holding time to analysis: 14 days.
Method of analysis: Gas Chromatography/Mass Spec.

(1) Specific detection limits are highly matrix dependent. The detection limits listed herein are provided for guidance and may not always be achievable. Lower detection levels are possible with additional work at an increased price.

(2) Detection limits listed for soil/sediment are based on wet weight.

CanonieEnvironmental

Table II
Semivolatile Organics (GC/MS)

Analytes	Detection Limits	
	Water (mg/l)(1)	Soil (mg/kg)(2)
Acenaphthene	0.010	0.330
Acenaphthylene	0.010	0.330
Aldrin	0.010	0.330
Anthracene	0.010	0.330
Benzo(a)anthracene	0.010	0.330
Benzo(b)fluoranthene	0.010	0.330
Benzo(k)fluoranthene	0.010	0.330
Benzo(ghi)perylene	0.010	0.330
Benzo(a)pyrene	0.010	0.330
Benzidine	0.040	1.32
Butyl benzyl phthalate	0.010	0.330
alpha-BHC	0.010	0.330
beta-BHC	0.010	0.330
delta-BH	0.010	0.330
gamma-BHC	0.010	0.330
Bis (2-chloroethoxy)methane	0.010	0.330
Bis (2-chloroethyl) ether	0.010	0.330
Bis (2-chloroisopropyl)ether	0.010	0.330
Bis (2-ethylhexyl)phthalate	0.010	0.330
4-Bromophenyl phenyl ether	0.010	0.330
Chlordane	0.100	3.30
4-Chloro-3-methylphenol	0.010	0.330
2-Choronaphthalene	0.010	0.330
2-Chlorophenol	0.010	0.330
4-Chlorophenyl phenyl ether	0.010	0.330
Chrysene	0.010	0.330
4,4'-DDD	0.010	0.330
4,4'-DDE	0.010	0.330
4,4'-DDT	0.010	0.330
Dibenzo(a,h)anthracene	0.010	0.330
Dibutyl phthalate	0.010	0.330
1,2-Dichlorobenzene	0.010	0.330
1,3-Dichlorobenzene	0.010	0.330

CanonieEnvironmental

Table II
Semivolatile Organics (GC/MS)

Analytes	Detection Limits Water (mg/l)(1)	Soil (mg/kg)(2)
1,4-Dichlorobenzene	0.010	0.330
3,3'-dichlorobenzidine	0.20	6.60
2,4-Dichlorophenol	0.010	0.330
Dieldrin	0.010	0.330
Diethylphthalate	0.010	0.330
2,4-Dimethylphenol	0.010	0.330
Dimethylphthalate	0.010	0.330
2,4-Dinitrophenol	0.050	1.65
2,4-Dinitrotoluene	0.010	0.330
2,6-Dinitrotoluene	0.010	0.330
Di-n-octylphthalate	0.010	0.330
Endosulfan I	0.010	0.330
Endosulfan II	0.010	0.330
Endosulfan sulfate	0.020	0.660
Endrin	0.010	0.330
Endrin aldehyde	0.020	0.660
Fluoranthene	0.010	0.330
Fluorene	0.010	0.330
Heptachlor	0.010	0.330
Heptachlor epoxide	0.010	0.330
Hexachlorobenzene	0.010	0.330
Hexachlorobutadiene	0.010	0.330
Hexachlorocyclopentadiene	0.010	0.330
Hexachloroethane	0.010	0.330
Indeno(1,2,3-cd)pyrene	0.010	0.330
Isophorone	0.010	0.330
2-Methyl-4,6-dinitrophenol	0.050	1.65
Naphthalene	0.010	0.330
Nitrobenzene	0.010	0.330
4-Nitrophenol	0.010	0.330
2-Nitrophenol	0.010	0.330
N-Nitrosodimethylamine	0.010	0.330
N-Nitrosodi-n-propylamine	0.010	0.330
N-Nitrosidiphenylamine	0.010	0.330

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Table II
Semivolatile Organics (GC/MS)

Analytes	Detection Limits	
	Water (mg/l)(1)	Soil (mg/kg)(2)
PCB-1016	0.050	1.65
PCB-1221	0.050	1.65
PCB-1232	0.050	1.65
PCB-1242	0.050	1.65
PCB-1248	0.050	1.65
PCB-1254	0.050	1.65
PCB-1260	0.050	1.65
Pentachlorophenol	0.050	1.65
Phenanthrene	0.010	0.330
Phenol	0.010	0.330
Pyrene	0.010	0.330
Toxaphene	0.5	16.5
1,2,4-Trichlorobenzene	0.010	0.330
2,4,6-Trichlorophenol	0.010	0.330

Water
Analysis: Method 625
Sampling container: Specially prepared one liter bottle taken in triplicate.
Reference: Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater, PB83-201796, Method 625, U.S. Environmental Protection Agency, Cincinnati, OH, July 1982

Soil
Analysis: Method 8270
Sampling container: Specially prepared mason jar, 200 g soil required.
Reference: Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Method 8270, U.S. Environmental Protection Agency, 1982.

Shipping requirements: Packed in an iced cooler with chain-of-custody.
Samples are extracted within 7 days and completely analyzed with in 30 days of collection.
Method of analysis: GC/MS

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Table II
Semivolatile Organics (GC/MS)

(1) Specific detection limits are highly matrix dependent. The detection limits listed herein are provided for guidance and may not always be achievable. Lower detection levels are possible with additional work at an increased price.

(2) Detection limits listed for soil/sediment are based on wet weight.

CanonieEnvironmental

Table II
Carbamates

Analytes	Detection Limits	
	Water (mg/l)	Soil (mg/kg)
Aldicarb	0.05	1.
Carbaryl	0.05	1.
Carbofuran	0.05	1.
Diuron	0.05	1.
Linuron	0.05	1.
Methomyl	0.05	1.
Oxamyl	0.05	1.

Water
Analysis: Method 632
Sampling container: Specially prepared one liter sample bottles, taken in triplicate.
Reference: Method of Organic Chemical Analysis of Municipal and Industrial Wastewater, PB83-201798, Method 632, U. S. Environmental Protection Agency, Cincinnati, OH, July 1982.

Soil
Analysis: Method 632Mod
Sampling container: Specially prepared mason jar or brass tube (200 g soil required).
Reference: Modified Method 632 Test Method for Evaluating Solid Waste, Physical/Chemical Methods, adapted for soil.

Shipping requirements: Packed in an iced cooler, with chain-of-custody. Samples are extracted within 7 days and completely analyzed within 30 days of collection.
Method of analysis: Liquid Chromatography.

CanonieEnvironmental

Table II
Fumingants

Analytes	Detection Limits Water (mg/l)	Soil (mg/kg)
DBCP (Dibromochloropropane)	0.01	1.0
EDB (Ethylene Dibromide)	0.1	1.0

Water
Analysis: Method 2000
Sampling container: Specially prepared one liter sample bottles, taken in triplicate, for EDB only, use 40 ml vial (purge & trap technique).
Reference: Analysis of 1,2-dibrom -3- chloropropane in Water, California Department of Health Services Methods, p. 215.
Reference: Method for Organic Chemical Analysis of Municipal and Industrial Wastewater, PB83-201798, Method 601, U. S. Environmental Protection Agency, Cincinnati, Ohio, July 1982 (EDB only).

Soil: Method 2010
Sampling container: Air tight completely full brass tube.
Reference: Analysis of 1,2-dibrom -3- chloropropane in Water, California Department of Health Services Methods, p. 215.
Reference: Test Method for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Method 8010, U. S. Environmental Protection Agency, 1982 (EDB only).

Shipping requirements: Packed in an iced cooler, with chain-of-custody. Samples are extracted within 7 days and completely analyzed within 30 days of collection. EDB only using purge & trap technique, 14 days to analysis. Method of analysis: Gas Chromatography.

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Table II
Benzene, Toluene, Xylene
(Gasoline components)

Analytes	Detection Limits	
	Water (mg/l)	Soil (mg/kg)
Benzene	0.005	0.2
Xylene	0.005	0.2
Toluene	0.005	0.2
Other Hydrocarbons	0.005	0.2

Other analytes available upon request
EDB

Water
Analysis: Method 2500
Sampling container: Specially prepared acidified 40 ml volatiles vials, taken in triplicate.
Reference: Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater, PB83-201798, Method 602, U. S. Environmental Protection Agency, Cincinnati, OH, July 1982.

Soil
Analysis: Method 2510
Sampling container: Air tight completely full brass tube, or 40 ml vial
Reference: Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Method 8020, U. S. Environmental Protection Agency, 1982.

Shipping requirements: Packed in an iced cooler, with chain-of-custody.
Acceptable holding time to analysis: 14 days.
Method of analysis: Gas Chromatography with FID detector.

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Table II
Total Extractable Hydrocarbons
(Diesel/Fuel Oil Components)

	Detection Limits	
Analytes	Water (mg/l)	Soil (mg/kg)
Total Extractable Hydrocarbons	1.	10.

Water
Analysis: Method 2515
Sampling container: Specially prepared one liter sample bottles, taken in triplicate.
Reference: Method for Organic Chemical Analysis of Municipal and Industrial Wastewater, PB 83-201798, Method 602 modified, U. S. Environmental Protection Agency, Cincinnati, OH, July 1982.

Soil
Analysis: Method 2520
Sampling container: Air tight completely full brass tube or 40 ml vial
Reference: Analytical Procedures for the Detection and Quantitation of Total Petroleum Fuel Hydrocarbons and Fuel Constituents California Regional Water Quality Control Board, 11/8/1985.

Shipping requirements: Packed in an iced cooler, with chain-of-custody. Samples are extracted within 7 days and completely analyzed within 30 days of collection.
Method of analysis: Solvent extraction, Gas Chromatography with FID detector.

CanonieEnvironmental

Table II
EP Toxicity Pesticides

Analytes	Maximum Contaminant Level (mg/1 leachate)	Detection Limit
Endrin	0.02	All detection limit
Lindane	0.4	are one-tenth or
Methoxychlor	10.0	less of the
Toxaphene	0.5	maximum contaminant
2,4-D	10.0	level
2,4,5-TP	1.0	

Analysis: Method EPTP
Samples are extracted with acetic acid and the leachate is examined for the pesticides listed.
Sampling container: Specially cleaned mason jars for solids and sludges sample size 400 g, and liter containers for liquids.
Reference: Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, EP Toxicity, U. S. Environmental Protection Agency, 1982.
Varian Liquid Chromatography Procedure #88, Reverse Phase Separation of 2,4-D and Silvex in Waste Water, Varian Instruments, Walnut Creek, California
Shipping requirements: Packed in an iced cooler, with chain-of-custody.
Samples are extracted within 7 days and completely analyzed within 30 days collection.
Method of analysis: Gas and Liquid Chromatography.

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Table II
Title 22 Pesticides/Herbicides

Analytes	Detection Limit Water (mg/l)
Endrin	0.00005
Lindane	0.00005
Methoxychlor	0.001
Toxaphene	0.005
2,4-D	0.01
2,4,5-TP (Silvex)	0.001

Water
Analysis: Method T22P
Sampling container: Specially prepared one liter bottles taken in triplicate.
Reference: Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater, PB 83-201796, Method 608, U. S. Environmental Protection Agency, Cincinnati, OH, July 1982. Determination of Chlorinated Herbicides in Industrial and Municipal Wastewater, EPA-600/4-82-005, Method 615, EMSL, U. S. Environmental Protection Agency, Cincinnati, OH, July 1982.
Shipping requirements: Packed in an iced cooler, with chain-of-custody.
Samples are extracted within 7 days and completely analyzed within 30 days of collection.
Method of analysis: Gas Chromatography.

CanonieEnvironmental

Table II
Priority Pollutant Metals
Metals

Analytes	Detection Limits Water (mg/l)	Soil (mg/kg)
Antimony	0.02	5.
Arsenic	0.01	5.
Beryllium	0.005	0.75
Cadmium	0.005	1.
Chromium	0.005	5.
Copper	0.05	5.
Lead	0.005	5.
Mercury	0.001	0.2
Nickel	0.05	5.
Selenium	0.005	1.
Silver	0.01	5.
Thallium	0.01	5.
Zinc	0.01	5.

Samples are digested and analyzed for the 13 metals, according to EPA criteria, Federal Register, December 3, 1979.

Sampling container: Special acid-washed mason jars for solids and sludges sample size 400 g, and special acid-washed liter containers for liquids.

Reference: California Assessment Manual, January 1984, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Individual Metals Analysis, U. S. Environmental Protection Agency, 1982.

Shipping requirements: Packed in an iced cooler, with chain-of-custody.

Method of analysis: Atomic Absorption Spectrophotometry.

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Table II
California Assessment Manual Metals

Analytes (mg/l)	Regulatory Limits		Detection Limits	
	TTLC (mg/kg)	STLC (mg/l)	TTLC (mg/kg)	STLC
Arsenic	500	5	5.	0.1
Antimony	500	15	5.	0.1
Barium	10,000	100	5.	0.1
Beryllium	75	0.75	0.75	0.1
Cadmium	100	1	1.	0.1
Chromium III/VI*	2,500/500	560/5	5/5	0.1/0.1
Cobalt	8,000	80	5.	0.1
Copper	2,500	25	5.	0.1
Lead	1,000	5	5.	0.1
Mercury	20	0.2	0.2	0.1
Molybdenum	3,500	350	5.	0.1
Nickel	2,000	20	5.	0.1
Selenium	100	1	1.	0.1
Silver	500	5	5.	0.1
Thallium	700	7	5.	0.1
Vanadium	2,400	24	5.	0.1
Zinc	5,000	250	5.	0.1

Samples are either acid digested for total metal content (to be compared to TTLC regulatory values) or extracted with citrate buffer (to be compared to STLC regulatory values).

*Chromium values are reported as total chromium, the sum of the III and VI species.

Sampling container: Special acid-washed mason jars for solids and sludges (400 g sample size), and special acid-washed liter containers for liquids.

Reference: California Assessment Manual, January 1984, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Individual Metals Analysis as per, U. S. Environmental Protection Agency, Methods listed on pp. 28, 30.

Shipping requirements: Packed in an iced cooler, with chain-of-custody.

Method of analysis: Atomic Absorption Spectrophotometry.

CanonieEnvironmental

Table II
EP Toxicity Metals

Analytes	Maximum Contaminant Level (mg/1 leachate)	Detection Limit
Arsenic	5.0	0.1
Barium	100.0	0.1
Cadmium	1.0	0.1
Chromium (total)	5.0	0.1
Mercury	0.2	0.1
Lead	5.0	0.1
Selenium	1.0	0.1
Silver	5.0	0.1

Samples are extracted with acetic acid, and the leachate is examined for the eight metals listed.

Sampling container: Specially cleaned mason jars for solids and sludges, and liter containers for liquids.

Reference: Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, EP Toxicity, U. S. Environmental Protection Agency, 1982.

Shipping requirements: Packed in an iced cooler, with chain-of-custody.

Method of analysis: Atomic Absorption Spectrophotometry.

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Table II
EPA Methods
Atomic Absorption Analysis
Metals in Water

Element	Flame	Graphite Furnace	Hydride Generation	Cold Vapor	ICP
Aluminum	EPA 202.1	EPA 202.2			EPA 200.7
Antimony	EPA 204.1	EPA 204.2			EPA 200.7
Arsenic		EPA 206.2	EPA 206.3		
Barium	EPA 208.1	EPA 208.2			EPA 200.7
Beryllium	EPA 210.1	EPA 210.2			EPA 200.7
Cadmium	EPA 213.1	EPA 213.2			EPA 200.7
Calcium	EPA 215.1				EPA 200.7
Chromium (Total)	EPA 218.1	EPA 218.2			EPA 200.7
Cobalt	EPA 219.1	EPA 219.2			EPA 200.7
Copper	EPA 220.1	EPA 220.2			EPA 200.7
Iron	EPA 236.1	EPA 236.2			EPA 200.7
Lead	EPA 239.1	EPA 239.2			EPA 200.7
Magnesium	EPA 242.1				EPA 200.7
Manganese	EPA 243.1	EPA 243.2			EPA 200.7
Mercury				EPA 245.1	
Molybdenum	EPA 246.1	EPA 246.2			EPA 200.7
Nickel	EPA 249.1	EPA 249.2			EPA 200.7
Potassium	EPA 258.1				EPA 200.7
Selenium		EPA 270.2	EPA 270.3		
Silver	EPA 272.1	EPA 272.2			EPA 200.7
Sodium	EPA 273.1				EPA 200.7
Strontium*	303A				EPA 200.7
Thallium	EPA 279.1	EPA 279.2			EPA 200.7
Vanadium	EPA 286.1	EPA 286.2			EPA 200.7
Zinc	EPA 289.1	EPA 289.2			EPA 200.7

Reference: Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020,
EMSL, U. S. Environmental Protection Agency, 1979.
* Reference: Standard Methods for the Examination of Water and Wastewater, 16th
Edition, 1985.
Method of Analysis: Atomic Absorption Spectrophotometry.

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Table II
Minimum Detection Limits
Atomic Absorption Analysis
Metals in Water
mg/l

Element	Flame	Graphite Furnace	Hydride Generation	Cold Vapor
Aluminum	0.5	0.02		
Antimony	0.02	0.005	0.005	
Arsenic		0.01	0.003	
Barium	0.2	0.05		
Beryllium	0.04	0.0005		
Cadmium	0.02	0.0005		
Calcium	0.05			
Chromium (Total)	0.1	0.003		
Cobalt	0.05	0.005		
Copper	0.05	0.003		
Iron	0.05	0.01		
Lead	0.4	0.002		
Magnesium	0.02	0.001		
Manganese	0.01			
Mercury				0.001
Molybdenum	0.1	0.005		
Nickel	0.2	0.005		
Potassium	0.05			
Selenium		0.005	0.004	
Silver	0.02	0.001		
Sodium	0.05			
Strontium	0.02	0.002		
Thallium	0.1	0.003		
Vanadium	0.5	0.005		
Zinc	0.03	0.005		

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Table II
EPA Methods
Atomic Absorption Analysis
Metals in Soil

Element	Flame	Graphite Furnace	Hydride Generation	Cold Vapor
Aluminum				
Antimony	EPA 7040	EPA 7041		
Arsenic		EPA 7060	EPA 7061	
Barium	EPA 7080	EPA 7081		
Beryllium	EPA 7090	EPA 7091		
Cadmium	EPA 7130	EPA 7131		
Calcium				
Chromium (Total)	EPA 7190	EPA 7191		
Cobalt				
Copper	EPA 7210	EPA 7211		
Iron	EPA 7380	EPA 7381		
Lead	EPA 7420	EPA 7421		
Magnesium				
Manganese	EPA 7460	EPA 7461		
Mercury				EPA 7471
Molybdenum				
Nickel	EPA 7520	EPA 7521		
Potassium				
Selenium		EPA 7740	EPA 7741	
Silver	EPA 7760	EPA 7761		
Sodium	EPA 7770			
Strontium				
Thallium	EPA 7840	EPA 7841		
Vanadium	EPA 7910	EPA 7911		
Zinc	EPA 7950	EPA 7951		

Reference: California Assessment Manual, January 1984, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846.

Method of analysis: Atomic Absorption Spectrophotometry.

CanonieEnvironmental

Table II
Minimum Detection Limits
Atomic Absorption Analysis
Metals in Soil
mg/kg

Element	Flame	Graphite Furnace	Hydride Generation	Cold Vapor
Aluminum	50.	2.		
Antimony	20.	1.	1.	
Arsenic		1.	0.5	
Barium	20.	5.		
Beryllium	20.	0.5		
Cadmium	4.	0.5		
Calcium	20.			
Chromium (Total)	20.	0.5		
Cobalt	20.	0.5		
Copper	20.	0.5		
Iron	20.	1.		
Lead	40.	0.5		
Magnesium	20.			
Manganese	4.	0.2		
Mercury				0.2
Molybdenum	40.	0.5		
Nickel	20.	0.5		
Potassium	20.			
Selenium		1.	1.	
Silver	4.	0.2		
Sodium	20.			
Strontium	4.	0.2		
Thallium	20.	0.5		
Vanadium	80.	0.5		
Zinc	5.	0.5		

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SITE PLAN
WAUKEGAN HARBOR, WAUKEGAN, ILLINOIS

PREPARED FOR

MARTIN, CRAIG, CHESTER AND
SONNENSCHEIN - CHICAGO, ILLINOIS

Canonie Environmental

| DATE 1-23-88 | FIGURE 1 | DRAWING NUMBER |
| SCALE AS SHOWN | | 86 059 E76 |

DRAFT

OMC SAMPLING PROGRAM

SAMPLES RETURNED TO SITE

SAMPLES PREPARED FOR SHIPPING

SAMPLE ID TO SAMPLE CONTROL

ARE SAMPLE CONTAINERS REQUESTED ?

SCHEDULE INCOMING WORK

ARCHIVE REPORT AND RAW DATA

FINAL REPORT

SEND CONTAINERS TO SITE

LOG SAMPLES INTO LP BOOK

REPORT VALID AND COMPLETE ?

ARE SAMPLES ACCEPTABLE ?

CORRECTIONS ?

REPORT REVIEWED BY SECTION CHIEF

INSTRUMENTATION CALIBRATION

ANALYSIS

SAMPLE PREPARATION

TRACKING SHEETS TO APPROPRIATE SECTIONS

DATA ENTRY

INSTRUMENTATION OPERATING WITHIN LIMITS?

BLANK ANALYSIS

BLANK ACCEPTABLE ?

SAMPLE ANALYSIS

QC ACCEPTABLE ?

DATA REDUCTION

DATA REVIEW BY ANALYST

DATA REVIEW BY SECTION CHIEF

DATA VALID ?

LABORATORY SAMPLE AND DATA FLOW CHART
WAUKEGAN HARBOR, WAUKEGAN, ILLINOIS
PREPARED FOR

DRAFT

MARTIN, CRAIG, CHESTER, AND

SONNENSCHEIN — CHICAGO, ILLINOIS

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| DATE: 1-10-88 | FIGURE 3 | DRAWING NUMBER |
| SCALE: N.T.S. | | 86-059-871 |

DATA REVIEW AND REPORTING

·ated by Canonie Environmental Services Corp. are reviewed
ists from each of the various areas. If a second chemist
·iew the work, then the quality assurance officer will do
he quality assurance officer randomly reviews work from
y the documentation and reported results.

re checked when reviewing the work:
he calculations, identification, and reported units are
t.

ll the results obtained for the samples were within the
ı calibration range or were diluted into the working
.tion range.

re   meet acceptance criteria.

.ults are unacceptable, then the cause for the results
st be determined before the analysis can continue and
ı. In the event that the QC results fall outside of the
C comment sheet (see Attachment X) is issued, on which
ysı ınd the QA Officer make appropriate comments and

results are acceptable, the chemist initials the
sheets, and/or other generated data, and gives the
a second chemist for review and approval.

:he entire report is
information, data,
ɔperly documented,
ent.

.erated, proofread by
: who reviewed the
ıy County, State, or

nt for posting, and

CANONIE ENVIRONMENTAL

QA/QC COMMENT SHEET

METHOD_____   DATE ANALYZED_____

INSTRUMENT ID_____   LP NUMBER_____

ANALYST_____   CLIENT_____

PROBLEM:_____

_____

_____

_____

CORRECTIVE ACTIONS:_____

_____

_____

ION CHIEF_____   DATE_____

ANALYST_____   DATE_____

COMMENTS_____

_____

_____

_____

QA/QC DEPT._____   DATE_____

COMMENTS:_____

_____

_____

8.0 QUALITY CONTROL

The quality control program is the most essential element to determining the performance of the analytical measurements.

The quality control program involves the analysis of a blank, duplicate, and spiked sample with every set of ten samples or with each matrix type.

1. Analysis of Blank

   There are several different types of blanks that can be prepared and analyzed; reagent blank, travel blank, or field blank.

   a. A reagent blank is prepared using deionized water, purified soil, solvents, acids, or other reagents used in the preparation and analysis of the samples. All analyses are run using a reagent blank in order to verify that any positive results are not due to contamination from the laboratory. Blanks showing contamination above minimal detectable levels indicates process contamination that must be corrected.

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b. A travel blank is prepared by Canonie Environmental Services Corp. and transported to the field, along with the sample containers. The travel blank undergoes all of the same handling as a sample, e.g., placed in the same cooler at the time of sampling, thus showing if any contamination was picked up during transportation. Travel blanks will be used to assess the environment in which the bottles and samples underwent during transportation. The results from the travel blank are used to assess contamination encountered during transportation. Should contamination occur, corrective measures must be taken (i.e., monitoring, resampling).

c. A field blank is prepared at the sampling site and returned blind to the laboratory with the sample. The field blank is exposed to the same environmental factors as the samples and is a good test to see if contamination is picked up at the time of sampling. Field blanks are used to monitor sampling techniques and are usually analyzed as a blind QC sample.

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2. Analysis of Duplicates

The preferred method of duplication at Canonie Environmental Services Corp. is the analysis of a duplicate spike sample. A sample is chosen randorly, divided into equal aliquots, spiked with a known amount of the analyte and prepared for analysis. Duplicate samples are analyzed to determine the precision of the preparation and analytical techniques. Daily the relative percent difference (RPD) between the spike and duplicate spike are plotted (See attachment XI). Relative percent difference is calculated as:

$$RPD = \frac{\text{Amount in Spike 1} - \text{Amount in Spike 2}}{\dfrac{\text{Spike 1} + \text{Spike 2}}{2}} \times 100$$

3. Analysis of Spiked Samples

In order to assure the accuracy of the analytical procedure, a sample is randomly chosen and spiked with a known amount of the analyte to be tested. The increased value for a spiked sample resulting from the addition of the analyte at a known concentration compared to the value obtained for that same analyte in the unspiked sample determines the percent recovery.

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Daily, control charts are plotted and kept by instrument specific, matrix specific, and analyte specific (see Attachment XII). The percent recovery for a spike sample is calculated as follows:

$$\% \text{ Rec.} = \frac{\text{Amt. Found in Spiked Sample} - \text{Amt. Found in Sample}}{\text{Known Amount Added}} \times 100$$

4. Measurement of Method Detection Limits

Periodically, Canonie Environmental Services Corp. reevaluates its method detection limits (MDL) for each matrix type and for each method.

To determine the MDL, the methods prescribed by the EPA are employed. The MDL is defined as the minimum concentration of a substance that can be identified, measured, and reported with 99% confidence.

a. Procedure

   1. If the MDL is determined in water, a laboratory standard at a concentration 1 - 5 times that of the estimated MDL is analyzed.

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2. For other matricies: a standard 5 - 10 times that of
    the estimated MDL is analyzed.

3. The standard is analyzed seven times.

4. The MDL is calculated by finding the standard deviation
    of the results for all seven analyses and multipling
    the standard deviation by a factor of 3.143.

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R. P. D.

ANALYTE_____

LAB I.D.																	
DATE																	
OBS. VALUE																	
DUP. VALUE																	
R. P. D.																	

Attachment XI

UCL _134_   UWL _122_   AVE. _96_   LWL _74_   LCL _62_   STD. DEV. _12_

LAB I.D.															
DATE															
OBS. VALUE															
REC. VALUE															
% REC.															

134

122

96

74

62

Attachment XII

9.0 ESTABLISHMENT OF ACCEPTABLE LIMITS

Construction of a Control Chart or $\bar{X}$ Chart

A control chart is constructed on data produced in the laboratory for a specific analysis and instrument. It is a method of showing the precision of an analysis, based on common, simple statistical methods.

When a quality control sample of known concentration is analyzed a number of times, a series of analytical results are received which should bracket the known concentration in a Gaussian or normal distribution. The average ($\bar{X}$) is the sum of the results divided by the number of results.

$$\bar{X} = \frac{\sum x}{n}$$

The standard deviation (σ) is an indication of the spread of the results from the mean, or the precision of the analysis. This is defined as the square root of the sum of the differences between the average and each result, squared, divided by one less than the number of analysis.

$$\sigma = \sqrt{\frac{\sum (x-\bar{x})^2}{n-1}}$$

The proportion of results lying within any given range is related to the standard deviation. That is, 68% of the observations lie within $\bar{X} \pm 1\sigma$, 95% between $\bar{X} \pm 2\sigma$, and 99% between $\bar{X} \pm 3\sigma$, for large numbers of samples. This relationship becomes more precise as n increases, but is suitable for smaller populations (approximately 20).

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Once a quality control sample has been analyzed at least 20 times and the mean and standard deviation established, it is possible to predict the limits into which any further analysis of the sample will fall if the analysis is performed under identical conditions. For example, if a known QC sample is 10.0 ppb, the analysis may produce an $\bar{X}$ of 9.9 and of 1.0 for 20 results. Then 95% of the results of re-analysis will fall within 9.9 ± 2.0 or from 7.9 to 11.9. In like manner 99% of the results of reanalysis will fall within 9.9 ± 3.0, or from 6.9 to 12.9. These ranges are known as limits. The upper and lower warning limits are $\bar{X} \pm 2$, and the upper and lower control limits are $\bar{X} \pm 3$.

These limits can be used to construct a chart defining when an analysis is "in control." (See Attachment XII)

In order to construct a control chart, the following steps are necessary:

1. Analyze the quality control sample at least 20 times.

2. Collate the results, finding the average ($\bar{X}$) and the standard deviation ( ).

3. Set the upper warning limit at $\bar{X} + 2$, the lower warning limit at $\bar{X} - 2$.

4. Set the upper control limit at $\bar{X} + 3$ and the lower control limit at $\bar{X} - 3$.

5. Draw a control chart which delineates the average and the four limits.

6. Plot each subsequent quality control result on the chart to demonstrate the precision of that analysis. (See Attachment XII).

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10.0 ACCEPTANCE CRITERIA AND PROBLEMS

When an analysis is being performed, the analyst must verify immediately that the results generated for the quality control samples falls within the acceptance limits for that analysis.

The quality control sample indicates acceptable analysis values when it falls between the lower warning limit (LWL) and the upper warning limit (UWL). As long as the quality control sample falls within these limits the analysis will continue and results will be released to the client. If the quality control sample value falls between the control limit and warning limit (UCL and UWL or LCL and LWL), the analysis should be scrutinized as possibly out-of-control. The sample results are still acceptable at this point, however, if the control sample value remains between the control limit and warning limit for 5 consecutive days, the analysis is stopped and no data is released until the problem is resolved.

If the quality control sample value falls outside the control limits (UCL or LCL), this indicates an out-of-control situation. The analysis is stopped and no data is released until the reason for the problem has been identified and resolved. When an out-of-control situation occurs, the analyst is required to fill out a QA/QC comment sheet (see Attachment XIII) and submit it to both their immediate supervisor and the Quality Assurance Officer. After the problem has been corrected and shown that acceptable results are once again produced, samples will once again be analyzed and data will be released. Depending on the type of problem encountered, the problem and its solution will be documented.

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Not only are the control charts used to monitor the performance of the laboratory, the Quality Assurance Officer also monitors the laboratory performance by releasing blind quality assurance samples and by randomly reviewing particular analysis. In the event that the Quality Assurance Officer spots unacceptable practices, a formal notice (see Attachment XIII) is issued to the laboratory manager and the section supervisor in which the corrective actions must be implemented. The section supervisor must respond to the formal notice and correct any difficiencies.

Precision, Accuracy and Relative Error:

Precision refers to the reproducibility of a method when it is repeated on a homogeneous sample under controlled conditions.

The precision or reproducibility of a method shall be expressed as a percentage of the mean and is termed the relative standard deviation or coefficient of variation:

$$C_v = \frac{100}{X}$$

where

C_v = Relative standard deviation or coefficient of variation

= standard deviation

X = mean

Relative error expresses the difference between the measured and the actual amounts:

$$\text{relative error} = \frac{X - TV}{X}$$

where
X = observed value
TV = true value
X = mean

Therefore, relative error represents the measure of accuracy of a method.

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QA/QC COMMENT SHEET

METHOD_____   DATE ANALYZED_____

INSTRUMENT ID_____   LP NUMBER_____

ANALYST_____   CLIENT_____

PROBLEM:_____

_____

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CORRECTIVE ACTIONS:_____

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ION CHIEF_____ DATE_____

ANALYST_____ DATE_____

COMMENTS_____

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QA/QC DEPT._____ DATE_____

COMMENTS:_____

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Attachment XIII

11.0 PERFORMED AND SYSTEM AUDITS

Canonie Environmental Services Laboratory routinely analyzes performance audit samples from both New York State Department of Health for potable and non-potable water and US EPA for both the drinking water (WS series) and wastewater (WP series) samples.

Certified reference materials are purchased from the National Bureau of Standards for metals in sediment like matrixs. Additional reference material is accquired from the US EPA Quality Assurance Materials Book.

3. Current laboratory certification include:

1. California DOHS certification for the analysis of Hazardous Waste.

2. California Department of Health Service, Sanitation and Radiation, approved water laboratory certification for General Chemical and Organic Chemical.

3. New York State Department of Health certification for potable water and non-potable water analysis.

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12.0 REVIEW OF ANALYTICAL RESULTS BY THE QUALITY ASSURANCE OFFICER

The function of the Quality Assurance Officer is to assure that the quality of the service delivered to the client meets the highest possible standard of quality, through the control of handling and analytical procedures performed on the samples. Should the acquired data be of suspect quality, it is the duty of the Quality Assurance Officer to halt its release.

Outlined is the functions and responsibilities performed by the Quality Assurance Officer:

1. Coordinate proficiency testing for laboratory approval programs.

2. Coordinate any on-site QA/QC inspections.

3. Prepare and update QA/QC plans.

4. Assist in the development of new analytical methods and techniques.

5. Assist in the development and planning of QA/QC documents and programs with the Project Engineer on a project by project basis.

6. With the QC committee continue to develop and implement a QC program.

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7. Monitor the sections for compliance to the QA/QC program by:

    - reviewing standard storage and preparation

    - reviewing instrument log books

    - reviewing QC documentation for completeness

    - reviewing sample storage

8. Analyze data generated from in-house QC check samples.

9. Advise personnel on laboratory procedures.

10. Advise personnel when problems are encountered with an
     analysis.

11. Respond to inquiries made regarding laboratory QA/QC related
     activities.

RESPONSIBILITIES: The Quality Assurance Officer will:

1. Identify and refer any instances in which QC objectives are not
    being met to the section heads and laboratory manager for
    remedial actions.

2. Assure that suspect data are not included in laboratory
    reports.

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3. Follow up on the remedial actions undertaken in response to the above referrals to assure that QC objectives are once again being met.

4. Inspect corrective action reports for out-of-control events.

5. Prepare a monthly QA report summarizing any warning sheets issued, corrective actions taken, unresolved problems, and overall QC activities of the laboratory.

A monthly QA report is then submitted to the Manager of Laboratory Services, Ken Wahl. He reviews the progress of the laboratory, makes his recommendations and goals for the next month. The monthly QA report is submitted to the Executive Vice President, Phillip E. Antommaria.

APPENDIX B

DAILY FIELD ACTIVITY LOG

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Daily Field
Activity Log

PROJECT No._____

DATE _____

PAGE_____OF_____

PROJECT NAME_____

FIELD ACTIVITY SUBJECT_____

WEATHER_____LOGGED BY_____

DAILY ACTIVITIES AND EVENTS:

APPENDIX B

LONG-TERM WATER TREATMENT FACILITY
SAMPLING FREQUENCY

When the long-term water treatment facility is running continuously, a sample will be taken monthly for the first year, then quarterly thereafter at a sampling point at the influent to the treatment unit and at a sampling point between the two carbon units. If the treatment facility is running on an intermittent basis, at least one sample will be collected between the two carbon canisters at both the startup and completion of each intermittent run.

The quarterly sampling frequency between the carbon canisters is sufficient to maintain the PCB discharge goal. Treating 500 gallons per day of ground water containing the solubility limit of 288 ppb PCB (Waid, John S., PCBs and the Environment, Volume I, CRC Press, Inc., 1986) will require 9.1 years to exhaust a 200 lb. carbon adsorption treatment container at two weight percent PCB loading. The calculation is presented with the following equations:

Weight of carbon per carbon adsorption container: 200 lb.

Water flow rate to long-term treatment facility: 500 gallons/day

Solubility limit of Aroclor 1242 in water: 288 ppb

PCB loading on carbon: $\dfrac{0.02 \text{ lbs. PCB}}{\text{lbs. carbon}}$

PCB removal rate:

$$500 \ \frac{\text{gallons water}}{\text{day}} \times \frac{8.34 \text{ lbs. water}}{\text{gallon water}} \times \frac{288 \text{ lbs. PCBs}}{1 \text{ billon lbs. water}} \times \frac{365 \text{ days}}{\text{year}} =$$

$0.438 \ \dfrac{\text{lbs. PCB}}{\text{year}}$

PCB capacity of 200 lbs. carbon:

$$200 \text{ lbs. carbon} \times \frac{0.02 \text{ lbs. PCB}}{\text{lbs. carbon}} = 4.0 \text{ lbs. PCBs}$$

Time required to achieve carbon loading:

4.0 lbs. PCB/$\dfrac{\text{0.438 lbs. PCBs}}{\text{year}}$ = 9.1 years

APPENDIX C

TEST PROCEDURES FOR SOILS ANALYSIS
AND MATERIAL SPECIFICATIONS

APPENDIX C

TEST PROCEDURES FOR SOILS ANALYSIS AND MATERIAL SPECIFICATIONS

ASTM Number	Subject
D1586	Standard Penetration Test
D4220	Sample Preservation
D2113	Diamond Core Drilling
D1785	PVC Pipe
D2216	Moisture Content Test
D422	Grain Size Test
D1140	200 Wash Sieve
D698	Standard Proctor Test
D2435	One-Dimensional Consolidation Test
D4318	Atterberg Limit Test

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Standard Method for

PENETRATION TEST AND SPLIT-BARREL SAMPLING OF SOILS[1]

1. Scope

1.1 This method describes the procedure, generally known as the Standard Penetration Test (SPT), for driving a split-barrel sampler to obtain a representative soil sample and a measure of the resistance of the soil to penetration of the sampler.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For a specific precautionary statement, see 5.4.1.*

1.3 The values stated in inch-pound units are to be regarded as the standard.

2. Applicable Documents

2.1 *ASTM Standards:*

D 2487 Test Method for Classification of Soils for Engineering Purposes[2]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]

D 4220 Practices for Preserving and Transporting Soil Samples[2]

3. Descriptions of Terms Specific to This Standard

3.1 *anvil*—that portion of the drive-weight assembly which the hammer strikes and through which the hammer energy passes into the drill rods.

3.2 *cathead*—the rotating drum or windlass in the rope-cathead lift system around which the operator wraps a rope to lift and drop the hammer by successively tightening and loosening the rope turns around the drum.

3.3 *drill rods*—rods used to transmit downward force and torque to the drill bit while drilling a borehole.

3.4 *drive-weight assembly*—a device consisting of the hammer, hammer fall guide, the anvil, and any hammer drop system.

3.5 *hammer*—that portion of the drive-weight assembly consisting of the 140 ± 2 lb (63.5 ± 1 kg) impact weight which is successively lifted and dropped to provide the energy that accomplishes the sampling and penetration.

3.6 *hammer drop system*—that portion of the drive-weight assembly by which the operator accomplishes the lifting and dropping of the hammer to produce the blow.

3.7 *hammer fall guide*—that part of the drive-weight assembly used to guide the fall of the hammer.

3.8 *N-value*—the blowcount representation of the penetration resistance of the soil. The N-value, reported in blows per foot, equals the sum of the number of blows required to drive the sampler over the depth interval of 6 to 18 in. (150 to 450 mm) (see 7.3).

3.9 *ΔN*—the number of blows obtained from each of the 6-in. (150-mm) intervals of sampler penetration (see 7.3).

3.10 *number of rope turns*—the total contact angle between the rope and the cathead at the beginning of the operator's rope slackening to drop the hammer, divided by 360° (see Fig. 1).

3.11 *sampling rods*—rods that connect the drive-weight assembly to the sampler. Drill rods are often used for this purpose.

3.12 *SPT*—abbreviation for Standard Penetration Test, a term by which engineers commonly refer to this method.

4. Significance and Use

4.1 This method provides a soil sample for identification purposes and for laboratory tests appropriate for soil obtained from a sampler that may produce large shear strain disturbance in the sample.

4.2 This method is used extensively in a great variety of geotechnical exploration projects. Many local correlations and widely published correlations which relate SPT blowcount, or N-value, and the engineering behavior of earthworks and foundations are available.

5. Apparatus

5.1 *Drilling Equipment*—Any drilling equipment that provides at the time of sampling a suitably clean open hole before insertion of the sampler and ensures that the penetration test is performed on undisturbed soil shall be acceptable. The following pieces of equipment have proven to be suitable for advancing a borehole in some subsurface conditions.

5.1.1 *Drag, Chopping, and Fishtail Bits,* less than 6.5 in. (162 mm) and greater than 2.2 in. (56 mm) in diameter may be used in conjuction with open-hole rotary drilling or casing-advancement drilling methods. To avoid disturbance of the underlying soil, bottom discharge bits are not permitted; only side discharge bits are permitted.

5.1.2 *Roller-Cone Bits,* less than 6.5 in. (162 mm) and greater than 2.2 in. (56 mm) in diameter may be used in conjunction with open-hole rotary drilling or casing-advancement drilling methods if the drilling fluid discharge is deflected.

5.1.3 *Hollow-Stem Continuous Flight Augers,* with or without a center bit assembly, may be used to drill the boring. The inside diameter of the hollow-stem augers shall be less than 6.5 in. (162 mm) and greater than 2.2 in. (56 mm).

5.1.4 *Solid, Continuous Flight, Bucket and Hand Augers,* less than 6.5 in. (162 mm) and greater than 2.2 in. (56 mm) in diameter may be used if the soil on the side of the boring does not cave onto the sampler or sampling rods during sampling.

5.2 *Sampling Rods*—Flush-joint steel drill rods shall be used to connect the split-barrel sampler to the drive-weight assembly. The sampling rod shall have a stiffness (moment of inertia) equal to or greater than that of parallel wall "A" rod (a steel rod which has an outside diameter of 1⅝ in. (41.2 mm) and an inside diameter of 1¼ in. (28.5 mm).

NOTE 1—Recent research and comparative testing indicates the type rod used, with stiffness ranging from "A" size rod to "N" size rod, will usually have a negligible effect on the N-values to depths of at least 100 ft (30 m).

5.3 *Split-Barrel Sampler*—The sampler shall be constructed with the dimensions indicated in Fig. 2. The driving shoe shall be of hardened steel and shall be replaced or repaired when it becomes dented or distorted. The use of liners to produce a constant inside diameter of 1⅜ in. (35 mm) is permitted, but shall be noted on the penetration record if used. The use of a sample retainer basket is permitted, and should also be noted on the penetration record if used.

NOTE 2—Both theory and available test data suggest that N-values may increase between 10 to 30 % when liners are used.

5.4 *Drive-Weight Assembly:*

5.4.1 *Hammer and Anvil*—The hammer shall weigh 140 ± 2 lb (63.5 ± 1 kg) and shall be a solid rigid metallic mass. The hammer shall strike the anvil and make steel on steel contact when it is dropped. A hammer fall guide permitting a free fall shall be used. Hammers used with the cathead and rope method shall have an unimpeded overlift capacity of at least 4 in. (100 mm). For safety reasons, the use of a hammer assembly with an internal anvil is encouraged.

NOTE 3—It is suggested that the hammer fall guide be permanently marked to enable the operator or inspector to judge the hammer drop height.

5.4.2 *Hammer Drop System*—Rope-cathead, trip, semi-automatic, or automatic hammer drop systems may be used, providing the lifting apparatus will not cause penetration of the sampler while re-engaging and lifting the hammer.

5.5 *Accessory Equipment*—Accessories such as labels, sample containers, data sheets, and groundwater level measuring devices shall be provided in accordance with the requirements of the project and other ASTM standards.

6. Drilling Procedure

6.1 The boring shall be advanced incrementally to permit intermittent or continuous sampling. Test intervals and locations are normally stipulated by the project engineer or geologist. Typically, the intervals selected are 5 ft (1.5 mm) or less in homogeneous strata with test and sampling locations at every change of strata.

6.2 Any drilling procedure that provides a suitably clean and stable hole before insertion of the sampler and assures that the penetration test is performed on essentially undisturbed soil shall be acceptable. Each of the following procedures have proven to be acceptable for some subsurface conditions. The subsurface conditions anticipated should be considered when selecting the drilling method to be used.

6.2.1 Open-hole rotary drilling method.

6.2.2 Continuous flight hollow-stem auger method.

6.2.3 Wash boring method.

6.2.4 Continuous flight solid auger method.

6.3 Several drilling methods produce unacceptable borings. The process of jetting through an open tube sampler and then sampling when the desired depth is reached shall not be permitted. The continuous flight solid auger method shall not be used for advancing the boring below a water table or below the upper confining bed of a confined non-cohesive stratum that is under artesian pressure. Casing may not be advanced below the sampling elevation prior to sampling. Advancing a boring with bottom discharge bits is not permissible. It is not permissible to advance the boring for subsequent insertion of the sampler solely by means of previous sampling with the SPT sampler.

6.4 The drilling fluid level within the boring or hollow-stem augers shall be maintained at or above the in situ groundwater level at all times during drilling, removal of drill rods, and sampling.

7. Sampling and Testing Procedure

7.1 After the boring has been advanced to the desired sampling elevation and excessive cuttings have been removed, prepare for the test with the following sequence of operations.

7.1.1 Attach the split-barrel sampler to the sampling rods and lower into the borehole. Do not allow the sampler to drop onto the soil to be sampled.

7.1.2 Position the hammer above and attach the anvil to the top of the sampling rods. This may be done before the sampling rods and sampler are lowered into the borehole.

7.1.3 Rest the dead weight of the sampler, rods, anvil, and drive weight on the bottom of the boring and apply a seating blow. If excessive cuttings are encountered at the bottom of the boring, remove the sampler and sampling rods from the boring and remove the cuttings.

7.1.4 Mark the drill rods in three successive 6-in. (0.15-m) increments so that the advance of the sampler under the impact of the hammer can be easily observed for each 6-in. (0.15-m) increment.

7.2 Drive the sampler with blows from the 140-lb (63.5-kg) hammer and count the number of blows applied in each 6-in. (0.15-m) increment until one of the following occurs:

7.2.1 A total of 50 blows have been applied during any one of the three 6-in. (0.15-m) increments described in 7.1.4.

7.2.2 A total of 100 blows have been applied.

7.2.3 There is no observed advance of the sampler during the application of 10 successive blows of the hammer.

7.2.4 The sampler is advanced the complete 18 in. (0.45 m) without the limiting blow counts occurring as described in 7.2.1, 7.2.2, or 7.2.3.

7.3 Record the number of blows required to effect each 6 in. (0.15 m) of penetration or fraction thereof. The first 6 in. is considered to be a seating drive. The sum of the number of blows required for the second and third 6 in. of penetration is termed the "standard penetration resistance", or the "N-value". If the sampler is driven less than 18 in. (0.45 m), as permitted in 7.2.1, 7.2.2, or 7.2.3, the number of blows per each complete 6-in. (0.15-m) increment and per each partial increment shall be recorded on the boring log. For partial increments, the depth of penetration shall be reported to the nearest 1 in. (25 mm), in addition to the number of blows. If the sampler advances below the bottom of the boring under the static weight of the drill rods or the weight of the drill rods plus the static weight of the hammer, this information should be noted on the boring log.

7.4 The raising and dropping of the 140-lb (63.5-kg) hammer shall be accomplished using either of the following two methods:

7.4.1 By using a trip, automatic, or semi-automatic hammer drop system which lifts the 140-lb (63.5-kg) hammer and allows it to drop 30 ± 1.0 in. (0.76 m ± 25 mm) unimpeded.

7.4.2 By using a cathead to pull a rope attached to the hammer. When the cathead and rope method is used the system and operation shall conform to the following:

7.4.2.1 The cathead shall be essentially free of rust, oil, or grease and have a diameter in the range of 6 to 10 in. (150 to 250 mm).

7.4.2.2 The cathead should be operated at a minimum speed of rotation of 100 RPM, or the approximate speed of rotation shall be reported on the boring log.

7.4.2.3 No more than 2¼ rope turns on the cathead may be used during the performance of the penetration test, as shown in Fig. 1.

NOTE 4—The operator should generally use either 1¾ or 2¼ rope turns, depending upon whether or not the rope comes off the top (1¾ turns) or the bottom (2¼ turns) of the cathead. It is generally known and accepted that 2¼ or more rope turns considerably impedes the fall of the hammer and should not be used to perform the test. The cathead rope should be maintained in a relatively dry, clean, and unfrayed condition.

7.4.2.4 For each hammer blow, a 30-in. (0.76-m) lift and drop shall be employed by the operator. The operation of pulling and throwing the rope shall be performed rhythmically without holding the rope at the top of the stroke.

7.5 Bring the sampler to the surface and open. Record the percent recovery or the length of sample recovered. Describe the soil samples recovered as to composition, color, stratification, and condition, then place one or more representative portions of the sample into sealable moisture-proof containers (jars) without ramming or distorting any apparent stratification. Seal each container to prevent evaporation of soil moisture. Affix labels to the containers bearing job designation, boring number, sample depth, and the blow count per 6-in. (0.15-m) increment. Protect the samples against extreme temperature changes. If there is a soil change within the sampler, make a jar for each stratum and note its location in the sampler barrel.

8. Report

8.1 Drilling information shall be recorded in the field and shall include the following:

8.1.1 Name and location o.

8.1.2 Names of crew,

8.1.3 Type and make of drilling machine,

8.1.4 Weather conditions,

8.1.5 Date and time of start and finish of boring,

8.1.6 Boring number and location (station and coordinates, if available and applicable),

8.1.7 Surface elevation, if available,

8.1.8 Method of advancing and cleaning the boring,

8.1.9 Method of keeping boring open,

8.1.10 Depth of water surface and drilling depth at the time of a noted loss of drilling fluid, and time and date when reading or notation was made,

8.1.11 Location of strata changes,

8.1.12 Size of casing, depth of cased portion of boring,

8.1.13 Equipment and method of driving sampler,

8.1.14 Type sampler and length and inside diameter of barrel (note use of liners),

8.1.15 Size, type, and section length of the sampling rods, and

8.1.16 Remarks.

8.2 Data obtained for each sample shall be recorded in the field and shall include the following:

8.2.1 Sample depth and, if utilized, the sample number,

8.2.2 Description of soil,

8.2.3 Strata changes within sample,

8.2.4 Sampler penetration and recovery lengths, and

8.2.5 Number of blows per 6-in. (0.15-m) or partial increment.

9. Precision and Bias

9.1 Variations in N-values of 100 % or more have been observed when using different standard penetration test apparatus and drillers for adjacent borings in the same soil formation. Current opinion, based on field experience, indicates that when using the same apparatus and driller, N-values in the same soil can be reproduced with a coefficient of variation of about 10 %.

9.2 The use of faulty equipment, such as an extremely massive or damaged anvil, a rusty cathead, a low speed cathead, an old, oily rope, or massive or poorly lubricated rope sheaves can significantly contribute to differences in N-values

obtained between operator-drill rig systems.

9.3 The variability in *N*-values produced by different drill rigs and operators may be reduced by measuring that part of the hammer energy delivered into the drill rods from the sampler and adjusting *N* on the basis of comparative energies. A method for energy measurement and *N*-value adjustment is currently under development.

(a) counterclockwise rotation approximately 1¾ turns

(b) clockwise rotation approximately 2¼ turns

Section A-A

Operator here

Rope

Cathead

Section B-B

Operator here
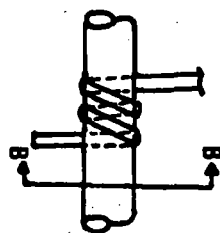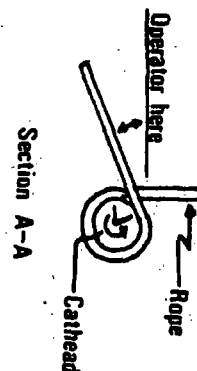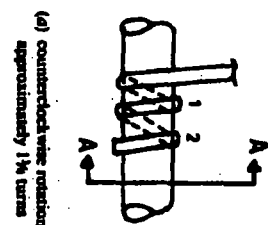
FIG. 1 Definitions of the Number of Rope Turns and the Angle for (a) Counterclockwise Rotation and (b) Clockwise Rotation of the Cathead

OPEN SHOE   HEAD   ROLLPIN

E   F   C   D   A   G   B

TUBE   BALL   VENT

(2 at ⅜ in. diameter.)
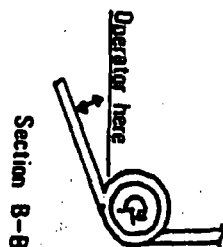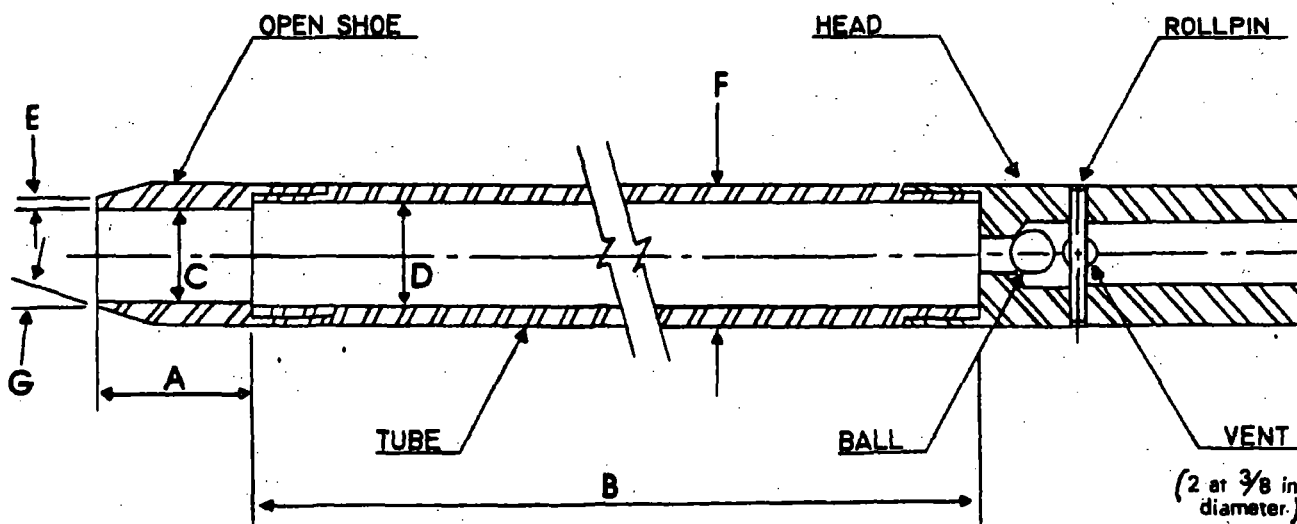
A = 1.0 to 2.0 in. (25 to 50 mm)
B = 18.0 to 30.0 in. (0.457 to 0.762 m)
C = 1.375 ± 0.005 in. (34.93 ± 0.13 mm)
D = 1.50 ± 0.05 − 0.00 in. (38.1 ± 1.3 − 0.0 mm)
E = 0.10 ± 0.02 in. (2.54 ± 0.25 mm)
F = 2.00 ± 0.05 − 0.00 in. (50.8 ± 1.3 − 0.0 mm)
G = 16.0° to 23.0°

The 1½ in. (38 mm) inside diameter split barrel may be used with a 16-gage wall thickness split liner. The penetrating end of the drive shoe may be slightly rounded. Metal or plastic retainers may be used to retain soil samples.

FIG. 2 Split-Barrel Sampler

Standard Practices for
PRESERVING AND TRANSPORTING SOIL SAMPLES[1]

This standard is issued under the fixed designation D 4220; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last approval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These practices set forth methods for preserving soil samples immediately after they are obtained in the field and accompanying methods for transporting and handling the samples.

1.2 These practices may include the handling and transporting of soil samples contaminated with hazardous materials and samples subject to quarantine regulations.

2. Applicable Documents

2.1 *ASTM Standards:*

D 420 Recommended Practice for Investigating and Sampling Soil and Rock for Engineering Purposes[2]

D 1452 Practice for Soil Investigation and Sampling by Auger Borings[2]

D 1586 Method for Penetration Test and Split-Barrel Sampling of Soils[2]

D 1587 Practice for Thin-Walled Tube Sampling of Soils[2]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]

D 3550 Practice for Ring-Lined Barrel Sampling of Soils[2]

3. Summary of Practices

3.1 The various methods are given under four groupings as follows:

3.1.1 *Group A*—Samples for which only general visual identification is necessary.

3.1.2 *Group B*—Samples for which only water content and classification tests, Proctor and relative density, or profile logging is required, and bulk samples that will be remolded or compacted into specimens for swell pressure, percent swell, consolidation, permeability, shear testing, CBR, stabilometer, etc.

3.1.3 *Group C*—Intact, naturally formed or field fabricated, samples for density determinations; or for swell pressure, percent swell, consolidation, permeability testing, and shear testing with or without stress-strain and volume change measurements, to include dynamic and cyclic testing.

3.1.4 *Group D*—Samples that are fragile or highly sensitive for which tests in Group C are required.

3.2 The method(s) to be used should be included in the project specifications or defined by the designated responsible person.

4. Significance and Use

4.1 Use of the various methods in these practices is dependent on the type of samples obtained, the type of testing and engineering properties required, the fragility and sensitivity of the soil, and the climatic conditions. In all cases, the primary purpose is to preserve the desired inherent conditions.

4.2 The methods presented in these practices were primarily developed for soil samples that are to be tested for engineering properties, however, they may be applicable for samples of soil and other materials obtained for other purposes.

5. Apparatus

5.1 The type of materials and containers needed depend upon the conditions and re-

quirements listed under the four groupings A to D in Section 3 and also on the climate and transporting mode and distance.

5.1.1 *Sealing Wax*, includes microcrystalline wax, paraffin, beeswax, ceresine, carnaubawax, or combinations thereof.

5.1.2 *Metal Disks*, about ⅟₁₆ in. (2 mm) thick and having a diameter slightly less than the inside diameter of the tube, liner, or ring and to be used in union with wax or caps and tape, or both.

5.1.3 *Wood Disks*, prewaxed, 1 in. (25 mm) thick, and having a diameter slightly less than the inside diameter of the liner or tube.

5.1.4 *Tape*, either waterproof plastic, adhesive friction, or duct tape.

5.1.5 *Cheesecloth*, to be used in union with wax in alternate layers.

5.1.6 *Caps*, either plastic, rubber, or metal, to be placed over the ends of thin-walled tubes, liners, and rings, in union with tape or wax.

5.1.7 *Packers*, used to seal the ends of samples within thin-walled tubes.

NOTE 1—Plastic expandable packers are preferred. Metal expandable packers seal equally well; however, long-term storage may cause corrosion problems.

5.1.8 *Jars*, wide-mouthed, with rubber-ringed lids or lids lined with a coated paper seal and of a size to comfortably receive the sample, commonly ½ pt (250 mL), 1 pt (500 mL), and quart sized (1000 mL).

5.1.9 *Bag*, either plastic, burlap with liner, burlap, or cloth type.

5.1.10 *Packing*—Material to protect against vibration and shock.

5.1.11 *Insulation*, either granule (bead), sheet, or foam type, to resist temperature change of soil or to prevent freezing.

5.1.12 *Sample Cube Boxes*, for transporting cube (block) samples and constructed with ½ to ¾-in. (13 to 19-mm) thick plywood (Marine type).

5.1.13 *Cylindrical Sample Containers*, somewhat larger in dimension than the thin-walled tube or liner samples, such as cylindrical frozen food cartons.

5.1.14 *Shipping Containers*, either box or cylindrical type and of proper construction to protect against vibration, shock, and the elements, to the degree required.

NOTE 2—The length, girth, and weight restrictions for commercial transportation must be considered.

5.1.15 *Identification Material*—This includes the necessary writing pens, tags, and labels to properly identify the sample(s).

6. Precautions

6.1 *Preserving and transporting soil samples may involve contact with hazardous materials, operations, and equipment. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

6.2 Special instructions, descriptions, and marking of containers must accompany any sample that may include radioactive chemical, toxic, or other contaminant material.

6.3 Interstate transportation containment, storage, and disposal of soil samples obtained from certain areas within the United States and the transportation of foreign soils into or through the United States are subject to regulations established by the U. S. Dept. of Agriculture, Animal and Plant Health Service, Plant Protection, and Quarantine Programs, and possibly to regulations of other Federal, state, or local agencies.

7. Procedure

7.1 *All Samples*—Properly identify samples with tags, labels, and markings prior to transporting them as follows:

7.1.1 Job name or number, or both,

7.1.2 Sampling date,

7.1.3 Sample/boring number and location,

7.1.4 Depth or elevation, or both,

7.1.5 Sample orientation,

7.1.6 Special shipping or laboratory handling instructions, or both, including sample orientation, and

7.1.7 Penetration test data, if applicable.

7.2 *Group A:*

7.2.1 Transport samples in any type of container by way of any available transportation. If transported commercially, the container need only meet the minimum requirements of the transporting agency and any other requirements necessary to assure against sample loss.

7.3 *Group B:*

7.3.1 These samples shall be preserved and transported in sealed, moistureproof containers. All containers shall be of sufficient thickness and strength to assure against breakage. The container types include: plastic bags

or pails, glass or plastic (provided they are waterproof) jars, thin-walled tubes, liners, and rings. Cylindrical and cube samples may be wrapped in suitable plastic film or aluminum foil, or both, (Note 3) and coated with several layers of wax, or sealed in several layers of cheesecloth and wax.

7.3.2 These samples may be transported by any available transportation. They may be shipped as prepared or placed in larger shipping containers, including bags, cardboard or wooden boxes, or barrels.

NOTE 3—Some soils may cause holes to develop in aluminum foil, due to corrosion. Avoid direct contact where adverse effects to sample composition are a concern.

7.3.3 *Plastic Bags*—The plastic bags should be placed as tightly as possible around the sample, squeezing out as much air as possible. They shall be 3 mil or thicker to prevent leakage.

7.3.4 *Glass-Plastic Jars*—If the jar lids are not rubber ringed or lined with new waxed paper seals, the lids must be sealed with wax.

7.3.5 *Plastic Pails*—If the plastic pail lids are not air tight, they must be sealed with wax.

7.3.6 *Thin-Walled Tubes:*

7.3.6.1 *Expandable Packers*—The preferred method of sealing sample ends within tubes is with plastic expandable packers.

7.3.6.2 *Wax with Disks*—For short-term sealing, paraffin wax is acceptable. For long-term sealing (in excess of 3 days), use microcrystalline waxes or combine them with up to 15 % beeswax or rosin for better adherence to the wall of the tube and to reduce shrinkage. Several thin layers of wax are preferred over one thick layer. The minimum final thickness shall be 0.4 in. (10 mm).

7.3.6.3 *End Caps*—Metal, rubber, or plastic end caps should be sealed with tape. For long-term storage (longer than 3 days), they shall also be dipped in wax, applying two or more layers.

7.3.6.4 *Cheesecloth and Wax*—Alternating layers (a minimum of two each) of cheesecloth and wax may be used to seal each end of the tube and stabilize the sample.

NOTE 4—Where necessary, spacers or appropriate packing material, or both, must be placed prior to sealing the tube ends to provide the proper confinement.

7.3.7 *Liners and Rings:*

7.3.7.1 Refer to 7.3.6.3 or 7.3.6.4

7.3.8 *Exposed Samples:*

7.3.8.1 *Cylindrical, Cubical, or Other Samples Wrapped in Plastic*, such as polyethylene and polypropylene or foil should be further protected with a minimum of three coats of wax.

7.3.8.2 *Cylindrical and Cube Samples Wrapped in Cheesecloth and Wax*, shall be sealed with a minimum of three layers of each, placed alternately.

7.3.8.3 *Carton Samples (Frozen Food Cartons)*—Samples placed in these containers must be situated so that wax can be poured completely around the sample. The wax should fill the void between the sample and container wall. Generally, the samples should be wrapped in plastic or foil before being surrounded with wax.

7.4 *Group C:*

7.4.1 These samples must be preserved and sealed in containers as covered under 7.3. In addition, they must be protected against vibration and shock and protected from extreme heat or cold.

7.4.2 Samples transported by the sampling or testing agency personnel on automobile and truck cab seats need only be placed in cardboard boxes or similar containers into which the sealed samples fit snugly preventing bumping, rolling, dropping, etc.

7.4.3 For all other methods of transporting samples, including bus, parcel services, truck, boat, air, etc., it will be necessary to place the sealed samples in wood, metal, or other type of suitable shipping containers that provide cushioning or insulation, or both, for each sample and container. Transporting by any agency whose handling of containers is suspect shall be avoided.

7.4.4 The cushioning material (sawdust, rubber, polystyrene, urethane foam, or material with similar resiliency) should completely encase each sample. The cushioning between the samples and walls of the shipping containers should have a minimum thickness of 1 in. (25 mm). A minimum thickness of 2 in. (50 mm) shall be provided on the container floor.

7.4.5 When necessary, the samples should be shipped in the same position in which they were sampled. Otherwise, special conditions shall be provided such as freezing, controlled drainage, or sufficient confinement, or a combination thereof, of the soil.

7.5 *Group D:*

7.5.1 The requirements of 7.4 must be met, plus the following:

7.5.1.1 Samples should be handled in the same orientation in which they were sampled, including during transportation or shipping, with appropriate markings on the shipping container.

7.5.1.2 For all modes of private or commercial transportation, the loading, transporting, and unloading of the shipment containers should be supervised as much as possible by a qualified person.

NOTE 5—A qualified person may be an engineer, geologist, soil scientist, soils technician, or responsible person designated by the project manager.

7.6 *Shipping Containers*—See Figs. 1 to 6 for typical containers.

7.6.1 The following features should be included in the design of the shipping container for Groups C and D.

7.6.1.1 It should be reuseable,

7.6.1.2 It should be constructed so that the samples can be maintained, at all times, in the same position as when sampled or packed, or both,

7.6.1.3 It should include sufficient packing material to cushion or isolate, or both, the tubes from the adverse effects of vibration and shock, and

7.6.1.4 It should include sufficient insulating material to prevent freezing, sublimation, and thawing, or undesirable temperature changes.

7.6.2 *Wood Shipping Containers:*

7.6.2.1 Wood is preferred over metal. Outdoor (Marine) plywood having a thickness of ½ to ¾ in. (13 to 19 mm) may be used. The top (cover) should be hinged and latched or fastened with screws.

7.6.2.2 The cushioning requirements are given under 7.4.4.

7.6.2.3 For protection against freezing or extreme temperature variation, the entire shipping container should be lined with a minimum insulation thickness of 2 in. (50 mm).

7.6.3 *Metal Shipping Containers:*

7.6.3.1 The metal shipping containers must incorporate cushioning and insulation material to minimum thicknesses covered under 7.6.2, although slightly greater thicknesses would be appropriate. Alternatively, the cushion effect could be achieved with a spring suspension system or any other means that would provide similar protection.

7.6.4 *Styrene Shipping Containers:*

7.6.4.1 *Bulk Styrene*, with slots cut to the dimensions of the sample tube or liner. A protective outer box of plywood or reinforced cardboard is recommended.

7.6.5 *Other Containers:*

7.6.5.1 Containers constructed with laminated fiberboard, plastic, or reinforced cardboard outer walls, and properly lined, may also be used.

8. Report

8.1 The data obtained in the field shall be recorded and shall include the following:

8.1.1 Job name or number, or both,

8.1.2 Sampling date(s),

8.1.3 Sample/boring number(s) and location(s),

8.1.4 Depth(s) or elevation(s), or both,

8.1.5 Sample orientation,

8.1.6 Ground water observation, if any,

8.1.7 Method of sampling and penetration test data, if applicable,

8.1.8 Sample dimensions,

8.1.9 Soil description (see Practice D 2488),

8.1.10 Names of technician/crewman, engineer, project chief, etc.,

8.1.11 Weather conditions, and

8.1.12 General remarks.

9. Precision and Accuracy

9.1 These practices provide qualitative and general information only, therefore a precision and accuracy statement is not applicable.

Top & bottom must be screwed into place (top may be hinged and latched)

13¼" (343 mm) SQ. TOP & BOTTOM

14" (356 mm)

2" (51 mm) Typ.

10" (254 mm)

3½" (89 mm) Typ center of hole to edge of divider

18" (457 mm)

4" (102 mm) Dia. Hole (4 holes each, top & bottom dividers)

1/2" (13 mm) Dia. Rope Handle (one this side & one opposite side)

10" (254 mm)

Minimum of 7 nails in each long edge (preferably also glued with waterproof glue)

Padding
4" (102 mm) of urethane foam (or equivalent) in the bottom of the box. 1" (25 mm) around the tubes and on top.

Material
3/4" (19 mm) thick plywood (exterior grade)

FIG. 1 Shipping Box for 3-in. (76-mm) Thin-Walled Tubes

(a) Photo of Open Box For 5" (127 mm) Tubes

(b) Top View

(c) Front View
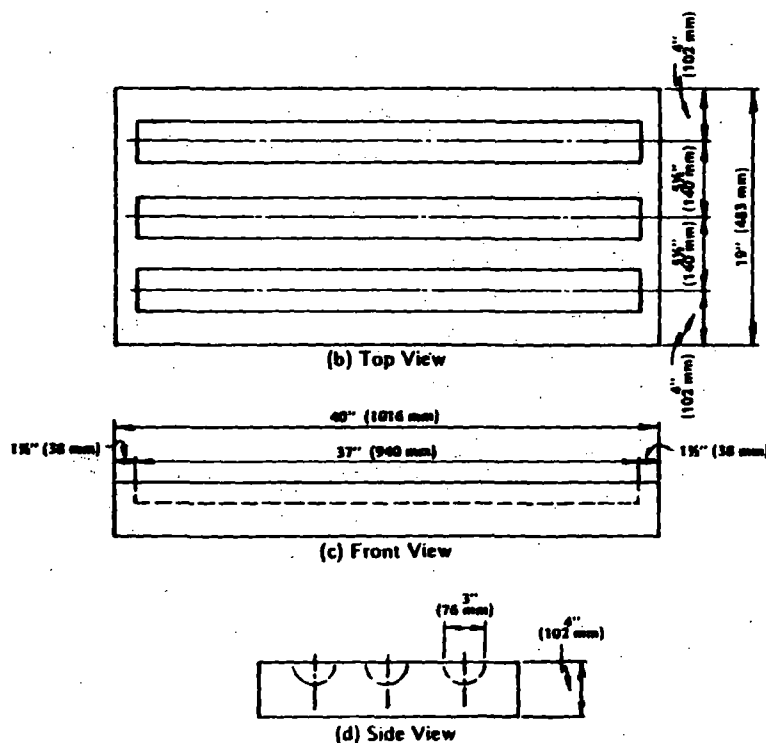
(d) Side View

NOTE—Top and bottom halves are identical.

FIG. 2   Styrene Shipping Container for 3-in. (76-mm) Thin-Walled Tubes
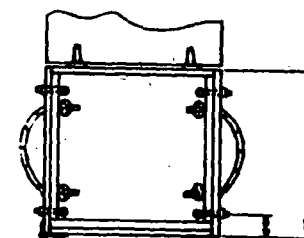
A.   TOP VIEW
(lid open)
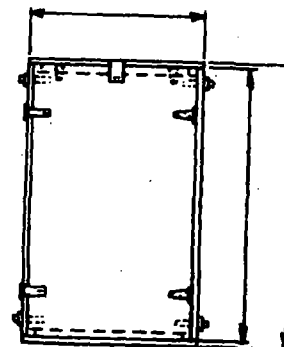
B.   FRONT VIEW
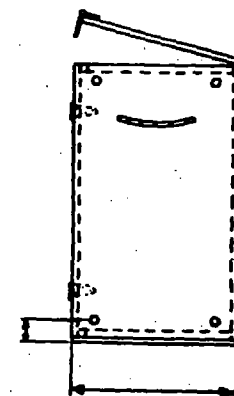
C.   SIDE VIEW

D.   PHOTOGRAPH OF OPEN BOX

BILL OF MATERIALS

Item No.	Description of Item	Quantity
1	Plywood, 4 ft by 8 ft by ¾ in. (1220 mm by 2440 mm by 19.1 mm) exterior, Grade AC	1 Sheet
2	Hinge, strap, 4 in. (102 mm), heavy duty with screws	4 Each
3	Hasp, hinged, 4½ in. (114 mm), with screws	3 Each
4	Screw, Wood, Steel, Flathead, No. 10 by 1¾ in. (44.5 mm)	72 Each
5	Bolt, Machine, ⅜ in. (9.5 mm), with nut to secure hasps	3 Each
6	Washer, flat, ⅜ in. (9.5 mm)	3 Each
7	Eye Bolt, ¼ by 2 in. (6.4 mm by 51 mm), zinc-plated, with nut	8 Each
8	Washer, flat, ¼ in. (6.4 mm), for hasp bolt	8 Each
9	S Hooks, 2 in. (51 mm), open, zinc-plated	8 Each
10	Clamp, adjustable, hose, steel, worm screw adjustment	2 Each
11	Spring, expansion	8 Each
12	Adhesive, woodworking	1 lb (454 g)
13	Rope, nylon, ½-in. (12.7-mm) diameter, solid braided	5 ft (1524 mm)
14	Cushioning Material, expanded polystyrene foam	10 ft³ (0.28 m³)

NOTE—(a) All wooden components can be sawed from one sheet of plywood.

(b) This shipping box will accommodate approximately three 3-in. (76-mm) diameter tubes or two 5-in. (127-mm) diameter tubes up to 30 in. (762 mm) in length. For longer tubes the inside height of the box must be a minimum of 6-in. (152 mm) greater than the length of the tube.

(c) All joints to be glued and fastened with screws.

(d) Stencil all sides as follows (See Views B and C).

UP   PROTECT FROM FREEZING

(e) After suspending samples as indicated above, all void space must be filled with a suitable resilient packing material.

FIG. 3   Suspension System Container for Thin-Walled Tubes
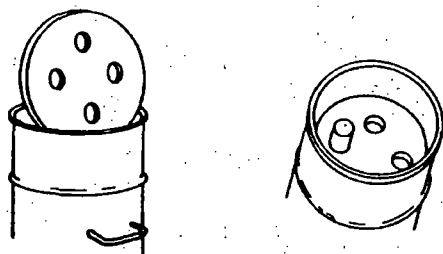
(a) 55-gallon (0.21 m^3) oil barrels
with sections of styrofoam insula-
tion; welded handles on each side.

Semi Sponge Rubber
1" (25mm) top and all side
surfaces; or, 2½" (64 mm)
insulation.

3/4" (19 mm) Binding Steel

18 Gauge Galvanized Steel
1" x 1½" (25 mm x 38 mm)

3" (76 mm) foam rubber over base; or
1" (25 mm) foam rubber and 2½" (64 mm)
insulation over base.

FIG. 5   Shipping Box for Liner (Short Tube) or Ring Samples

(b) Same as (a) showing barrel ready
for shipment. Steel lids bolted
on to provide tight seal.

NOTE—Two in. (51 mm) of foam rubber covers 2 in. of styrofoam at the base. One in. (25 mm) of foam rubber overlays
the top of the tubes, and the remaining space to the lid is filled with styrofoam.

FIG. 4   Shipping Barrel for Thin-Walled Tubes

litional laye._ of cheese
and warm rubbed wax
are required to seal
the sample.

One thickness of cheese cloth
is placed against soil, follow
by an application of warm wax,
rubbed by hand.

A.   METHOD FOR SEALING HAND-CUT UNDISTURBED SAMPLES

Fill space between sealed
sample and box with moist
sawdust packed to support
sample.
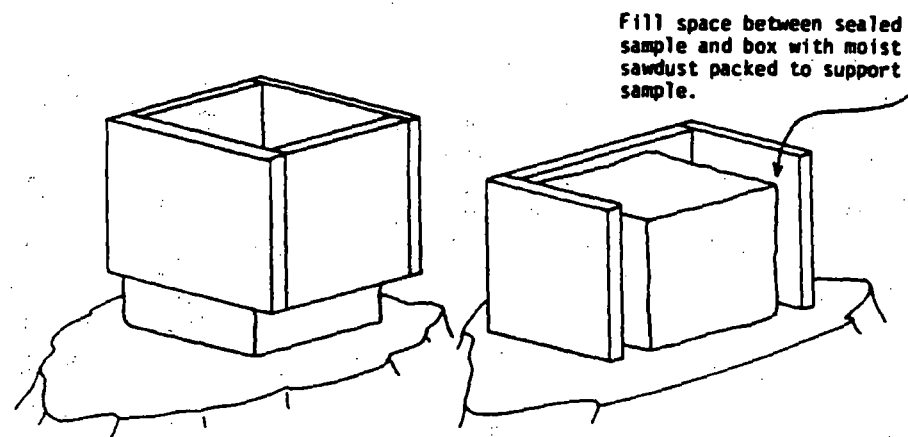
B.   ENCASE EASILY DISTURBED SAMPLES IN BOX PRIOR TO CUTTING

Box constructed with 1/2"-3/4" (13 - 19 mm) exterior plywood.

FIG. 6   Preparing and Packaging a Block Sample

Standard Practice for

DIAMOND CORE DRILLING FOR SITE INVESTIGATION[1]

This standard is issued under the fixed designation D 2113; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice describes equipment and procedures for diamond core drilling to secure core samples of rock and some soils that are too hard to sample by soil-sampling methods. This method is described in the context of obtaining data for foundation design and geotechnical engineering purposes rather than for mineral and mining exploration.

2. Applicable Documents

2.1 ASTM Standards:

D 1586 Method for Penetration Test and Split-Barrel Sampling of Soils[2]

D 1587 Practice for Thin-Walled Tube Sampling of Soils[2]

D 3550 Practice for Ring-Lined Barrel Sampling of Soils[2]

3. Significance and Use

3.1 This practice is used to obtain core specimens of superior quality that reflect the in-situ conditions of the material and structure and which are suitable for standard physical-properties tests and structural-integrity determination.

4. Apparatus

4.1 Drilling Machine, capable of providing rotation, feed, and retraction by hydraulic or mechanical means to the drill rods.

4.2 Fluid Pump or Air Compressor, capable of delivering sufficient volume and pressure for the diameter and depth of hole to be drilled.

4.3 Core barrels as required:

4.3.1 Single Tube Type, WG Design, consisting of a hollow steel tube, with a head at one end threaded for drill rod, and a threaded connection for a reaming shell and core bit at the other end. A core lifter, or retainer located within the core

bit is normal, but may be omitted at the discretion of the geologist or engineer.

4.3.2 Double Tube, Swivel-Type, WG Design—An assembly of two concentric steel tubes joined and supported at the upper end by means of a ball or roller-bearing swivel arranged to permit rotation of the outer tube without causing rotation of the inner tube. The upper end of the outer tube, or removable head, is threaded for drill rod. A threaded connection is provided on the lower end of the outer tube for a reaming shell and core bit. A core lifter located within the core bit is normal but may be omitted at the discretion of the geologist or engineer.

4.3.3 Double-Tube, Swivel-Type, WT Design, is essentially the same as the double tube, swivel-type, WG design, except that the WT design has thinner tube walls, a reduced annular area between the tubes, and takes a larger core from the same diameter bore hole. The core lifter is located within the core bit.

4.3.4 Double Tube, Swivel Type, WM Design, is similar to the double tube, swivel-type, WG design, except that the inner tube is threaded at its lower end to receive a core lifter case that effectively extends the inner tube well into the core bit, thus minimizing exposure of the core to the drilling fluid. A core lifter is contained within the core lifter case on the inner tube.

4.3.5 Double Tube Swivel-Type, Large-Diameter Design, is similar to the double tube, swivel-type, WM design, with the addition of a

ball valve, to control fluid flow, in all three available sizes and the addition of a sludge barrel, to catch heavy cuttings, on the two larger sizes. The large-diameter design double tube, swivel-type, core barrels are available in three core per hole sizes as follows: 2¾ in. (69.85 mm) by 3⅞ in. (98.43 mm), 4 in. (101.6 mm) by 5½ in. (139.7 mm), and 6 in. (152.4 mm) by 7¾ in. (196.85 mm). Their use is generally reserved for very detailed investigative work or where other methods do not yield adequate recovery.

4.3.6 *Double Tube, Swivel-Type, Retrievable Inner-Tube Method,* in which the core-laden inner-tube assembly is retrieved to the surface and an empty inner-tube assembly returned to the face of the borehole through the matching, large-bore drill rods without need for withdrawal and replacement of the drill rods in the borehole. The inner-tube assembly consists of an inner tube with removable core lifter case and core lifter at one end and a removable inner-tube head, swivel bearing, suspension adjustment, and latching device with release mechanism on the opposite end. The inner-tube latching device locks into a complementary recess in the wall of the outer tube such that the outer tube may be rotated without causing rotation of the inner tube and such that the latch may be actuated and the inner-tube assembly transported by appropriate surface control. The outer tube is threaded for the matching, large-bore drill rod and internally configured to receive the inner-tube latching device at one end and threaded for a reaming shell and bit, or bit only, at the other end.

4.4 *Longitudinally Split Inner Tubes*—As opposed to conventional cylindrical inner tubes, allow inspection of, and access to, the core by simply removing one of the two halves. They are not standardized but are available for most core barrels including many of the retrievable inner-tube types.

4.5 *Core Bits*—Core bits shall be surface set with diamonds, impregnated with small diamond particles, inserted with tungsten carbide slugs, or strips, hard-faced with various hard surfacing materials or furnished in saw-tooth form, all as appropriate to the formation being cored and with concurrence of the geologist or engineer. Bit matrix material, crown shape, water-way type, location and number of water ways, diamond size and carat weight, and bit facing materials shall be for general purpose use unless otherwise

approved by the geologist or engineer. Nominal size of some bits are shown in Table 1.

NOTE 1—Size designation (letter symbols) used throughout the text and in Tables 1, 2, and 3 are those standardized by the Diamond Core Drill Manufacturers' Assoc. (DCDMA). Inch dimensions in the tables have been rounded to the nearest hundredth of an inch.

4.6 *Reaming Shells,* shall be surface set with diamonds, impregnated with small diamond particles, inserted with tungsten carbide strips or slugs, hard faced with various types of hard surfacing materials, or furnished blank, all as appropriate to the formation being cored.

4.7 *Core Lifters*—Core lifters of the split-ring type, either plain or hard-faced, shall be furnished and maintained, along with core-lifter cases or inner-tube extensions or inner-tube shoes, in good condition. Basket or finger-type lifters, together with any necessary adapters, shall be on the job and available for use with each core barrel if so directed by the geologist or engineer.

4.8 *Casings:*

4.8.1 *Drive Pipe or Drive Casing,* shall be standard weight (schedule 40), extra-heavy (schedule 80), double extra-heavy (schedule 160) pipe or W-design flush-joint casing as required by the nature of the overburden or the placement method. Drive pipe or W-design casing shall be of sufficient diameter to pass the largest core barrel to be used, and it shall be driven to bed rock or to firm seating at an elevation below water-sensitive formation. A hardened drive shoe is to be used as a cutting edge and thread protection device on the bottom of the drive pipe or casing. The drive shoe inside diameter shall be large enough to pass the tools intended for use, and the shoe and pipe or casing shall be free from burrs or obstructions.

4.8.2 *Casing*—When necessary to case through formations already penetrated by the borehole or when no drive casing has been set, auxiliary casing shall be provided to fit inside the borehole to allow use of the next smaller core barrel. Standard sizes of telescoping casing are shown in Table 2. Casing bits have an obstruction in their interior and will not pass the next smaller casing size. Use a casing shoe if additional telescoping is anticipated.

4.8.3 *Casing Liner*—Plastic pipe or sheet-metal pipe may be used to line an existing large-diameter casing. Liners, so used, should not be driven, and care should be taken to maintain true

alignment throughout the length of the liner.

4.8.4 *Hollow Stem Auger*—Hollow stem auger may be used as casing for coring.

4.9 *Drill Rods:*

4.9.1 *Drill Rods of Tubular Steel Construction* are normally used to transmit feed, rotation, and retraction forces from the drilling machine to the core barrel. Drill-rod sizes that are presently standardized are shown in Table 3.

4.9.2 Large bore drill rods used with retrievable inner-tube core barrels are not standardized. Drill rods used with retrievable inner-tube core barrels should be those manufactured by the core-barrel manufacturer specifically for the core barrel.

4.9.3 *Composite Drill Rods* are specifically constructed from two or more materials intended to provide specific properties such as light weight or electrical nonconductivity.

4.9.4 *Nonmagnetic Drill Rods* are manufactured of nonferrous materials such as aluminum or brass and are used primarily for hole survey work. Some nonmagnetic rods have left-hand threads in order to further their value in survey work. No standard exists for nonmagnetic rods.

4.10 *Auxiliary Equipment,* shall be furnished as required by the work and shall include: roller rock bits, drag bits, chopping bits, boulder busters, fishtail bits, pipe wrenches, core barrel wrenches, lubrication equipment, core boxes, and marking devices. Other recommended equipment includes: core splitter, rod wicking, pump-out tools or extruders, and hand sieve or strainer.

5. Transportation and Storage of Core Containers

5.1 *Core Boxes,* shall be constructed of wood or other durable material for the protection and storage of cores while enroute from the drill site to the laboratory or other processing point. All core boxes shall be provided with longitudinal separators and recovered cores shall be laid out as a book would read, from left to right and top to bottom, within the longitudinal separators. Spacer blocks or plugs shall be marked and inserted into the core column within the separators to indicate the beginning of each coring run. The beginning point of storage in each core box is the upper left-hand corner. The upper left-hand corner of a hinged core box is the left corner when the hinge is on the far side of the box and the box is right-side up. All hinged core boxes must

be permanently marked on the outside to indicate the top and the bottom. All other core boxes must be permanently marked on the outside to indicate the top and the bottom and additionally, must be permanently marked internally to indicate the upper-left corner of the bottom with the letters UL or a splotch of red paint not less than 1 in.[2]. Lid or cover fitting(s) for core boxes must be of such quality as to ensure against mix up of the core in the event of impact or upsetting of the core box during transportation.

5.2 Transportation of cores from the drill site to the laboratory or other processing point shall be in durable core boxes so padded or suspended as to be isolated from shock or impact transmitted to the transporter by rough terrain or careless operation.

5.3 Storage of cores, after initial testing or inspection at the laboratory or other processing point, may be in cardboard or similar less costly boxes provided all layout and marking requirements as specified in 5.1 are followed. Additional spacer blocks or plugs shall be added if necessary at time of storage to explain missing core. Cores shall be stored for a period of time specified by the engineer but should not normally be discarded prior to completion of the project for which they were taken.

6. Procedure

6.1 Use core-drilling procedures when formations are encountered that are too hard to be sampled by soil-sampling methods. A 1-in. (25.4-mm) or less penetration for 50 blows in accordance with Method D 1586 or other criteria established by the geologist or engineer, shall indicate that soil-sampling methods are not applicable.

6.1.1 Seat the casing on bedrock or in a firm formation to prevent raveling of the borehole and to prevent loss of drilling fluid. Level the surface of the rock or hard formation at the bottom of the casing when necessary using the appropriate bits. Casing may be omitted if the borehole will stand open without the casing.

6.1.2 Begin the core drilling using an N-size double-tube swivel-type core barrel or other size or type approved by the engineer. Continue core drilling until core blockage occurs or until the net length of the core barrel has been drilled in. Remove the core barrel from the hole and disassemble it as necessary to remove the core. Reassemble the core barrel and return it to the hole. Resume coring.

6.1.3 Place the recovered core in the core box with the upper (surface) end of the core at the upper-left corner of the core box as described in 5.1. Continue boxing core with appropriate markings, spacers, and blocks as described in 5.1. Wrap soft or friable cores or those which change materially upon drying in plastic film or seal in wax, or both, when such treatment is required by the engineer. Use spacer blocks or slugs properly marked to indicate any noticeable gap in recovered core which might indicate a change or void in the formation. Fit fracture, bedded, or jointed pieces of core together as they naturally occurred.

6.1.4 Stop the core drilling when soft materials are encountered that produce less than 50 % recovery. If necessary, secure samples of soft materials in accordance with the procedures described in Method D 1586, Practice D 1587, or Practice D 3550, or by any other method acceptable to the geologist or engineer. Resume diamond core drilling when refusal materials as described in 6.1 are again encountered.

6.2 Subsurface structure, including the dip of strata, the occurrence of seams, fissures, cavities, and broken areas are among the most important items to be detected and described. Take special care to obtain and record information about these features. If conditions prevent the continued advance of the core drilling, the hole should be cemented and redrilled, or reamed and cased, or cased and advanced with the next smaller-size core barrel, as required by the geologist or engineer.

6.3 Drilling mud or grouting techniques must be approved by the geologist or engineer prior to their use in the borehole.

6.4 *Compatibility of Equipment:*

6.4.1 Whenever possible, core barrels and drill rods should be selected from the same letter-size designation to ensure maximum efficiency. See Tables 1 and 3.

6.4.2 Never use a combination of pump, drill rod, and core barrel that yields a clear-water up-hole velocity of less than 120 ft/min.

6.4.3 Never use a combination of air compressor, drill rod, and core barrel that yields a clear-air up-hole velocity of less than 3000 ft/min.

7. Boring Log

7.1 The boring log shall include the following:

7.1.1 Project identification, boring number, location, date boring began, date boring completed, and driller's name.

7.1.2 Elevation of the ground surface.

7.1.3 Elevation of or depth to ground water and raising or lowering of level including the dates and the times measured.

7.1.4 Elevations or depths at which drilling fluid return was lost.

7.1.5 Size, type, and design of core barrel used. Size, type, and set of core bit and reaming shell used. Size, type, and length of all casing used. Description of any movements of the casing.

7.1.6 Length of each core run and the length or percentage, or both, of the core recovered.

7.1.7 Geologist's or engineer's description of the formation recovered in each run.

7.1.8 Driller's description, if no engineer or geologist is present, of the formation recovered in each run.

7.1.9 Subsurface structure description, including dip of strata and jointing, cavities, fissures, and any other observations made by the geologist or engineer that could yield information regarding the formation.

7.1.10 Depth, thickness, and apparent nature of the filling of each cavity or soft seam encountered, including opinions gained from the feel or appearance of the inside of the inner tube when core is lost. Record opinions as such.

7.1.11 Any change in the character of the drilling fluid or drilling fluid return.

7.1.12 Tidal and current information when the borehole is sufficiently close to a body of water to be affected.

7.1.13 Drilling time in minutes per foot and bit pressure in pound-force per square inch gage when applicable.

7.1.14 Notations of character of drilling, that is, soft, slow, easy, smooth, etc.

8. Precision and Accuracy

8.1 This practice does not produce numerical data; therefore, a precision and accuracy statement is not applicable.

NOTE 2—Inclusion of the following tables and use of letter symbols in the foregoing text is not intended to limit the practice to use of DCDMA tools. The table and text references are included as a convenience to the user since the vast majority of tools in use do meet DCDMA dimensional standards. Similar equipment of approximately equal size on the metric standard system is acceptable unless otherwise stipulated by the engineer or geologist.

TABLE 1 Core Bit Sizes

Size Designation	Outside Diameter		Inside Diameter	
	in.	mm	in.	mm
RWT	1.16	29.5	0.375	18.7
EWT	1.47	37.3	0.905	22.9
EWG, EWM	1.47	37.3	0.845	21.4
AWT	1.88	47.6	1.281	32.5
AWG, AWM	1.88	47.6	1.185	30.0
BWT	2.35	59.5	1.750	44.5
BWG, BWM	2.35	59.5	1.655	42.0
NWT	2.97	75.3	2.313	58.7
NWG, NWM	2.97	75.3	2.155	54.7
2⅜ × 3⅞	3.84	97.5	2.69	68.3
HWT	3.89	98.8	3.187	80.9
HWG, ...	3.89	98.8	3.000	76.2
4 × 5½	5.44	138.0	3.97	100.8
6 × 7¼	7.66	194.4	5.97	151.6

TABLE 2 Casing Sizes

Size Designation	Outside Diameter		Inside Diameter		Threads per in.	Will Fit Hole Drilled with Core Bit Size
	in.	mm	in.	mm		
RW	1.144	36.5	1.19	30.1	5	EWT, EWG, EWM
EW	1.81	46.0	1.50	38.1	4	AWT, AWG, AWM
AW	2.25	57.1	1.91	48.4	4	BWT, BWG, BWM
BW	2.88	73.0	2.38	60.3	4	NWT, NWG, NWM
NW	3.50	88.9	3.00	76.2	4	HWT, HWG
HW	4.50	114.3	4.00	101.6	4	4 × 5½
PW	5.50	139.7	5.00	127.0	3	6 × 7¼
SW	6.63	168.2	6.00	152.4	3	6 × 7¼
UW	7.63	193.6	7.00	177.8	2	...
ZW	8.63	219.0	8.00	203.2	2	...

TABLE 3 Drill Rods

Size Designation	Rod and Coupling Outside Diameter		Rod Inside Diameter		Coupling Bore, Threads		
	in.	mm	in.	mm	in.	mm	per in.
RW	1.09	27.7	0.72	18.2	0.41	10.3	4
EW	1.38	34.9	1.00	25.4	0.44	11.1	3
AW	1.72	43.6	1.34	34.1	0.63	15.8	3
BW	2.13	53.9	1.75	44.4	0.75	19.0	3
NW	2.63	66.6	2.25	57.1	1.38	34.9	3
HW	3.50	88.9	3.06	77.7	2.38	60.3	3

Standard Specification for
POLY(VINYL CHLORIDE) (PVC) PLASTIC PIPE, SCHEDULES 40, 80, AND 120[1]

This standard is issued under the fixed designation D 1785; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This specification has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This specification covers poly(vinyl chloride) (PVC) pipe made in Schedule 40, 80, and 120 sizes and pressure-rated for water (see Appendix). Included are criteria for classifying PVC plastic pipe materials and PVC plastic pipe, a system of nomenclature for PVC plastic pipe, and requirements and test methods for materials, workmanship, dimensions, sustained pressure, burst pressure, flattening, and extrusion quality. Methods of marking are also given.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 The following precautionary caveat pertains only to the test method portion, Section 7, of this specification. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* A specific precautionary statement is given in Note 6.

NOTE 1—CPVC plastic pipes, Schedules 40 and 80, which were formerly included in this standard, are now covered by Specification F 441, Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe, Schedules 40 and 80.[5]

NOTE 2—The sustained and burst pressure test requirements, and the pressure ratings in the Appendix, are calculated from stress values obtained from tests made on pipe 4 in. (100 mm) and smaller. However, tests conducted on pipe as large as 24 in. (600 mm) diameter have shown these stress values to be valid for larger diameter PVC pipe.

NOTE 3—PVC pipe made to this specification is

often belled for use as line pipe. For details of the solvent cement belled pipe, see Specification D 2672 and for details of belled elastomeric joints, see Specifications D 3139 and D 3212.

2. Referenced Documents

2.1 *ASTM Standards:*

D 618 Methods of Conditioning Plastics and Electrical Insulating Materials for Testing[3]

D 1598 Test Method for Time-To-Failure of Plastic Pipe Under Constant Internal Pressure[2]

D 1599 Test Method for Short-Time Hydraulic Failure Pressure of Plastic Pipe, Tubing, and Fittings[2]

D 1600 Abbreviations of Terms Relating to Plastics[4]

D 1784 Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds[5]

D 2122 Method of Determining Dimensions of Thermoplastic Pipe and Fittings[2]

D 2152 Test Method for Degree of Fusion of Extruded Poly(Vinyl Chloride) Pipe and Molding Fittings by Acetone Immersion[2]

D 2672 Specification for Solvent Cement Joint Sockets on Belled PVC Pressure Pipe[2]

D2837 Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials[2]

D3139 Specification for Joints for Plastic Pressure Pipes Using Flexible Elastomeric Seals[2]

D3212 Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals[2]

F412 Definitions of Terms Relating to Plastic Piping Systems[2]

2.2 *Federal Standard:[4]*

Fed. Std. No. 123 Marking for Shipment (Civil Agencies)

2.3 *Military Standard:[4]*

MIL-STD-129 Marking for Shipment and Storage

3. Terminology

3.1 *Definitions:*

3.1.1 *General*—Definitions are in accordance with Definitions F412 and abbreviations are in accordance with Abbreviations D 1600, unless otherwise indicated. The abbreviation for poly(vinyl chloride) plastic is PVC.

3.2 *Descriptions of Terms Specific to This Standard:*

3.1.1 *hydrostatic design stress*—the estimated maximum tensile stress in the wall of the pipe in the circumferential orientation due to internal hydrostatic water pressure that can be applied continuously with a high degree of certainty that failure of the pipe will not occur.

3.1.2 *pressure rating (PR)*—the estimated maximum pressure that water in the pipe can exert continuously with a high degree of certainty that failure of the pipe will not occur.

3.1.3 *relation between dimensions, design stress, and pressure rating*—the following expression, commonly known as the ISO equation,[7] is used in this specification to relate dimensions, hydrostatic design stress, and pressure rating:

$$2S/P = (D_o/t) - 1$$

where:

S = hydrostatic design stress, psi (or MPa),

P = pressure rating, psi (or MPa),

D_o = average outside diameter, in. (or mm), and

t = minimal wall thickness, in. (or mm).

3.1.4 *standard thermoplastic pipe materials designation code*—the pipe materials designation code shall consist of the abbreviation PVC for the type of plastic, followed by the ASTM type

and grade in Arabic numerals and the design stress in units of 100 psi (0.7 MPa) with any decimal figures dropped. When the design stress code contains less than two figures, a cipher shall be used before the number. Thus a complete material code shall consist of three letters and four figures for PVC plastic pipe materials (see Section 5).

5. Materials and Manufacturer

5.1 *General*—Poly(vinyl chloride) plastics used to make pipe meeting the requirements of this specification are categorized by means of two criteria, namely, (*1*) short-term strength tests and (*2*) long-term strength tests.

NOTE 4—PVC pipe that is intended for use in the transport of potable water should be evaluated for this purpose by a laboratory recognized by the public health profession and by the regulatory bodies having jurisdiction. Many public health authorities recognize National Sanitation Foundation Standard No. 14 for Plastic Piping System Components and Related Materials, as a suitable standard to evaluate materials for potable water service. The seal or mark of the laboratory making the evaluation should be included in the marking on pipe that is intended for the transport of potable water. A laboratory that makes evaluations of pipe for transport of potable water is the National Sanitation Foundation Testing Laboratories, Inc., NSF Bldg., Ann Arbor, MI 48106. Names of other recognized laboratories will be added when they are brought to the attention of ASTM.

5.2 *Basic Materials*—This specification covers pipe made from PVC plastics having certain physical and chemical properties as described in Specification D 1784.

5.3 *Compound*—The PVC compounds used for this pipe shall equal or exceed the following classes described in Specification D 1784; PVC 12454-B, 12454-C, or 14333-D.

5.4 *Rework Material*—Clean, rework material of the same type and grade (cell classification), generated from the manufacturer's own pipe production, may be used by the same manufacturer, as long as the pipe produced meets all the requirements of this specification.

6. Requirements

6.1 *Dimensions and Tolerances:*

[4] Available from Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.
[7] ISO R161-1960, Pipes of Plastics Materials for the Transport of Fluids (Outside Diameters and Nominal Pressures) Part 1, Metric Series.

6.1.1 Dimensions and tolerances shall be as shown in Tables 1 and 2 when measured in accordance with Method D 2122. The tolerances for out-of-roundness shall apply only to pipe prior to shipment.

6.2 *Sustained Pressure*—The pipe shall not fail, balloon, burst, or weep as defined in Test Method D 1598, at the test pressures given in Tables 3, 4, or 5 when tested in accordance with 8.4.

6.2.1 *Accelerated Regression Test*—At the option of the manufacturer, an accelerated regression test may be substituted for the sustained pressure test. The test shall be conducted in accordance with 8.4.1. The pipe shall demonstrate a hydrostatic design basis projection at the 100 000 h intercept that meets the hydrostatic design basis category requirement (see Table 1 and Method D 2837) for the PVC material used in its manufacture. (*Example:* PVC 1120 pipe must have a minimum 100 000 h projection of 3830 psi (26.40 MPa) and 85 % lower confidence limit (LCL).

6.3 *Burst Pressure*—The minimum burst pressures for PVC plastic pipe shall be as given in Table 6, when determined in accordance with Test Method D 1599.

6.4 *Flattening*—There shall be no evidence of splitting, cracking, or breaking when the pipe is tested in accordance with 8.5.

6.5 *Extrusion Quality*—The pipe shall not flake or disintegrate when tested in accordance with Test Method D 2152.

7. Workmanship, Finish, and Appearance

7.1 The pipe shall be homogeneous throughout and free of visible cracks, holes, foreign inclusions, or other defects. The pipe shall be as uniform as commercially practicable in color, opacity, density, and other physical properties.

NOTE 5—Color and transparency or opacity should be specified in the contract or purchase order.

8. Test Methods

8.1 *Conditioning*—Condition the test specimens at 73.4 ± 3.6°F (23 ± 2°C) and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Methods D 618, for those tests where conditioning is required.

8.2 *Test Conditions*—Conduct tests in the Standard Laboratory Atmosphere of 73.4 ± 3.6°F

(23 ± 2°C) and 50 ± 5 % relative humidity, unless otherwise specified in the test methods or in this specification.

8.3 *Sampling*—The selection of the sample or samples of pipe shall be as agreed upon by the purchaser and seller. In case of no prior agreement, any sample selected by the testing laboratory shall be deemed adequate.

8.3.1 *Test Specimens*—Not less than 50 % of the test specimens required for any pressure test shall have at least a part of the marking in their central sections. The central section is that portion of pipe which is at least one pipe diameter away from an end closure.

8.4 *Sustained Pressure Test*—Select the test specimens at random. Test individually with water at the internal pressures given in Tables 3, 4, and 5, six specimens of pipe, each specimen at least ten times the nominal diameter in length, but not less than 10 in. (250 mm) or more than 3 ft (1 m) between end closures and bearing the permanent marking on the pipe. Maintain the specimens at the pressure indicated for a period of 1000 h. Hold the pressure as closely as possible, but within ±10 psi (±70 kPa). Condition the specimens at the test temperature of 73.4°F (23°C) to within 3.6°F (±2°C). Test in accordance with Test Method D 1598, except maintain the pressure at the values given in Tables 3, 4, or 5 for 1000 h. Failure of one of the six specimens tested is cause for retest of six additional specimens. Failure of one of the six specimens tested in retest shall constitute failure in the test. Evidence of failure of the pipe shall be as defined in Test Method D 1598.

8.4.1 *Accelerated Regression Test*—Test in accordance with procedures in Test Method D 1598, except that restrained-end fittings may be employed. A minimum of six samples will be tested at pressures selected to yield data points as follows:

    0.010 to 0.099 h (36 s to 6 min)
    0.10 to 0.999 h (6 min to 1 h)
    1.00 to 9.999 h
    10.0 to 99.999 h
    100 to 100+ h
    0 to 100+ h (random point)

Additional points may be added if necessary to improve projection or LCL, or both. No point shall be excluded unless an obvious defect is detected in the failure area of the test sample. Characterize the results using the least square extrapolation described in Method D 2837.

NOTE 6—Caution: Since rupture of the test specimen is expected in quick burst and high stress regression testing, well shielded test equipment and protective personal equipment should be used when conducting the tests.

8.5 *Burst Pressure*—Determine the minimum burst pressure with at least five specimens in accordance with Test Method D 1599. The time of testing of each specimen shall be between 60 and 70 s.

8.6 *Flattening*—Flatten three specimens of the pipe, 2 in. (50 mm) long, between parallel plates in a suitable press until the distance between the plates is 40 % of the outside diameter of the pipe or the walls of the pipe touch, whichever occurs first. The rate of loading shall be uniform and such that the compression is completed within 2 to 5 min. On removal of the load examine the specimens for evidence of splitting, cracking, or breaking.

9. Retest and Rejection

9.1 If any failure occurs, the materials may be retested to establish conformity in accordance with agreement between the purchaser and the seller.

10. Certification

10.1 The seal of the National Sanitation Foundation Testing Laboratory, Inc. indicates that the product is tested under the NSF certification program.

10.2 Certification and labeling, by other independent laboratories, may be accepted if approved by the code authority having jurisdiction.

11. Product Marking

11.1 *Quality of Marking*—The marking shall be applied to the pipe in such a manner that it remains legible (easily read) after installation and inspection.

11.2 *Content of Marking:*

11.2.1 Marking on the pipe shall include the following, spaced at intervals of not more than 5 ft (1.5 m):

11.2.1.1 Nominal pipe size (for example, 2 in. (50 mm)),

11.2.1.2 Type of plastic pipe material in accordance with the designation code prescribed in 4.5, for example, PVC1120,

11.2.1.3 Schedule (40, 80, or 120, whichever is applicable) and the pressure rating in pounds per square inch (megapascals) for water at 73°F (23°C) shown as the number followed by psi (for example, 200 psi (1.4 MPa)). When the indicated pressure rating is lower than that calculated in accordance with 3.4 (see Appendix), this shall be indicated by placing a star after the pressure rating,

11.2.1.4 ASTM designation D 1785, with which the pipe complies,

11.2.1.5 Manufacturer's name (or trademark) and code (see Note 3), and

11.2.1.6 Pipe intended for the transport of potable water shall also include the seal or mark of the laboratory making the evaluation for this purpose, spaced at intervals specified by the laboratory.

NOTE 7—Manufacturers using the seal or mark of a laboratory must obtain prior authorization from the laboratory concerned.

NOTE 8—It is common practice to dual mark Schedule 40 piping for potable water and DWV usage in which compliance with each applicable standard is met.

12. Quality Assurance

12.1 *Quality Assurance*—When the product is marked with this designation "ASTM D 1785", the manufacturer affirms that this product was inspected, sampled, and tested in accordance with this specification and has been found to meet the requirements of this specification.

proves. The purchaser shall have the right to perform any of the inspections and tests set forth in this specification where such inspections are deemed necessary to ensure that material conforms to prescribed requirements.

NOTE S1—In U.S. Federal contracts, the contractor is responsible for inspection.

S2. *Packaging and Marking for U.S. Government Procurement:*

S2.1 *Packaging*—Unless otherwise specified in the contract, the materials shall be packaged in accordance with the supplier's standard practice in a manner ensuring arrival at destination in satisfactory condition and which will be acceptable to the carrier at lowest rates. Containers and packing shall comply with Uniform Freight Classification rules or National Motor Freight Classification rules.

S2.2 *Marking*—Marking for shipment shall be in accordance with Fed. Std. No. 123 for military agencies.

NOTE S2—The inclusion of U.S. Government procurement requirements should not be construed as an indication that the U.S. Government uses or endorses the products described in this document.

TABLE 1 Outside Diameters and Tolerances for PVC Plastic Pipe Schedules 40, 80, and 120, in. (mm)

Nominal Pipe Size	Outside Diameter	Tolerances		
			For Maximum and Minimum Diameter (Out-of-Roundness)	
		Average	Schedule 40 sizes 3½ in. and over; Schedule 80 sizes 8 in. and over	Schedule 40 sizes 3 in. and less; Schedule 80 sizes 6 in. and less; Schedule 120 sizes all
¼	0.405 (10.29)	±0.004 (±0.10)	...	±0.008 (±0.20)
⅜	0.540 (13.72)	±0.004 (±0.10)	...	±0.008 (±0.20)
⅜	0.675 (17.14)	±0.004 (±0.10)	...	±0.008 (±0.20)
½	0.840 (21.34)	±0.004 (±0.10)	...	±0.008 (±0.20)
¾	1.050 (26.67)	±0.004 (±0.10)	...	±0.010 (±0.25)
1	1.315 (33.40)	±0.005 (±0.13)	...	±0.010 (±0.25)
1¼	1.660 (42.16)	±0.005 (±0.13)	...	±0.012 (±0.30)
1½	1.900 (48.26)	±0.006 (±0.15)	...	±0.012 (±0.30)
2	2.375 (60.32)	±0.006 (±0.15)	...	±0.012 (±0.30)
2½	2.875 (73.02)	±0.007 (±0.18)	...	±0.015 (±0.38)
3	3.500 (88.90)	±0.008 (±0.20)	...	±0.015 (±0.38)
3½	4.000 (101.60)	±0.008 (±0.20)	±0.050 (±1.27)	±0.015 (±0.38)
4	4.500 (114.30)	±0.009 (±0.23)	±0.050 (±1.27)	±0.015 (±0.38)
5	5.563 (141.30)	±0.010 (±0.25)	±0.050 (±1.27)	±0.030 (±0.76)
6	6.625 (168.28)	±0.011 (±0.28)	±0.050 (±1.27)	±0.035 (±0.89)
8	8.625 (219.08)	±0.015 (±0.38)	±0.075 (±1.90)	±0.045 (±1.14)
10	10.750 (273.05)	±0.015 (±0.38)	±0.075 (±1.90)	±0.050 (±1.27)
12	12.750 (323.85)	±0.015 (±0.38)	±0.075 (±1.90)	±0.060 (±1.52)

GOVERNMENT/MILITARY PROCUREMENT

These requirements apply *only* to Federal/Military procurement, not domestic sales or transfers.

S1. *Responsibility for Inspection*—Unless otherwise specified in the contract or purchase order, the producer is responsible for the performance of all inspection and test requirements specified herein. The producer may use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless the purchaser disap-

TABLE 2 Wall Thicknesses and Tolerances for PVC Plastic Pipe, Schedule 40, 80, and 120,[A,B] in. (mm)

Nominal Pipe Size	Wall Thickness[A]					
	Schedule 40		Schedule 80		Schedule 120	
	Minimum	Tolerance	Minimum	Tolerance	Minimum	Tolerance
⅛	0.068 (1.73)	+0.020 (+0.51)	0.095 (2.41)	+0.020 (+0.51)	...	...
¼	0.088 (2.24)	+0.020 (+0.51)	0.119 (3.02)	+0.020 (+0.51)	...	...
⅜	0.091 (2.31)	+0.020 (+0.51)	0.126 (3.20)	+0.020 (+0.51)	...	...
½	0.109 (2.77)	+0.020 (+0.51)	0.147 (3.73)	+0.020 (+0.51)	0.170 (4.32)	+0.020 (+0.51)
¾	0.113 (2.87)	+0.020 (+0.51)	0.154 (3.91)	+0.020 (+0.51)	0.170 (4.32)	+0.020 (+0.51)
1	0.133 (3.38)	+0.020 (+0.51)	0.179 (4.55)	+0.021 (+0.53)	0.200 (5.08)	+0.024 (+0.61)
1¼	0.140 (3.56)	+0.020 (+0.51)	0.191 (4.85)	+0.023 (+0.58)	0.215 (5.46)	+0.026 (+0.66)
1½	0.145 (3.68)	+0.020 (+0.51)	0.200 (5.08)	+0.024 (+0.61)	0.225 (5.72)	+0.027 (+0.68)
2	0.154 (3.91)	+0.020 (+0.51)	0.218 (5.54)	+0.026 (+0.66)	0.250 (6.35)	+0.030 (+0.76)
2½	0.203 (5.16)	+0.024 (+1.12)	0.276 (7.01)	+0.033 (+0.84)	0.300 (7.62)	+0.036 (+0.91)
3	0.216 (5.49)	+0.026 (+0.66)	0.300 (7.62)	+0.036 (+0.91)	0.350 (8.89)	+0.042 (+1.07)
3½	0.226 (5.74)	+0.027 (+0.68)	0.318 (8.08)	+0.038 (+0.96)	0.350 (8.89)	+0.042 (+1.07)
4	0.237 (6.02)	+0.028 (+0.71)	0.337 (8.56)	+0.040 (+1.02)	0.437 (11.10)	+0.052 (+1.32)
5	0.258 (6.55)	+0.031 (+0.79)	0.375 (9.52)	+0.045 (+1.14)	0.500 (12.70)	+0.060 (+1.52)
6	0.280 (7.11)	+0.034 (+0.86)	0.432 (10.97)	+0.052 (+1.32)	0.562 (14.27)	+0.067 (+1.70)
8	0.322 (8.18)	+0.039 (+0.99)	0.500 (12.70)	+0.060 (+1.52)	0.718 (18.24)	+0.086 (+2.18)
10	0.365 (9.27)	+0.044 (+1.12)	0.593 (15.06)	+0.071 (+1.80)	0.843 (21.41)	+0.101 (+2.56)
12	0.406 (10.31)	+0.049 (+1.24)	0.687 (17.45)	+0.082 (+2.08)	1.000 (25.40)	+0.120 (+3.05)

[A] The minimum is the lowest wall thickness of the pipe at any cross section. The maximum permitted wall thickness, at any cross section, is the minimum wall thickness plus the stated tolerance. All tolerances are on the plus side of the minimum requirement.

[B] These dimensions conform to nominal IPS dimensions, with the exception that Schedule 120 wall thickness for pipe sizes ½ to 3½ in. (12.5 to 87.5 mm), inclusive, are special PVC plastic pipe sizes.

TABLE 3 Sustained Pressure Test Conditions for Water at 73°F (23°C) for PVC Plastic Pipe, Schedule 40

Nominal Pipe Size	Pressure Required for Test[A]			
	PVC1120 PVC1220 PVC2120	PVC2116	PVC2112	PVC2110
in.	psi			
⅛	1690	1360	1130	930
¼	1640	1310	1090	900
⅜	1310	1050	870	720
½	1250	1000	840	690
¾	1010	810	680	550
1	950	760	630	520
1¼	770	620	520	420
1½	690	560	460	380
2	580	470	390	320
2½	640	510	430	350
3	590	440	370	300
3½	500	400	340	280
4	470	370	310	260
5	410	330	270	220
6	370	300	250	200
8	330	260	220	180
10	300	240	200	160
12	280	220	180	150
in.	MPa			
⅛	11.65	9.38	7.79	6.41
¼	11.31	9.03	7.52	6.21
⅜	9.03	7.24	6.00	4.96
½	8.62	6.89	5.79	4.76
¾	6.96	5.58	4.69	3.79
1	6.55	5.24	4.34	3.59
1¼	5.31	4.27	3.59	2.90
1½	4.76	3.86	3.17	2.62
2	4.00	3.24	2.69	2.21
2½	4.41	3.52	2.96	2.41
3	4.07	3.03	2.55	2.07
3½	3.45	2.76	2.34	1.93
4	3.24	2.55	2.14	1.79
5	2.83	2.28	1.86	1.52
6	2.55	2.07	1.72	1.38
8	2.28	1.79	1.52	1.24
10	2.07	1.65	1.38	1.10
12	1.93	1.52	1.24	1.03

[A] The fiber stresses used to derive these test pressures are as follows:

	psi	MPa
PVC1120	4200	29.0
PVC1220	4200	29.0
PVC2120	4200	29.0
PVC2116	3360	23.2
PVC2112	2800	19.3
PVC2110	2300	15.9

TABLE 4 Sustained Pressure Test Conditions for Water at 73°F (23°C) for PVC Plastic Pipe, Schedule 80

Nominal Pipe Size	Pressure Required for Test[A]			
	PVC1120 PVC1220 PVC2120	PVC2116	PVC2112	PVC2110
in.	psi			
⅛	2570	2060	1720	1410
¼	2370	1900	1580	1300
⅜	1930	1540	1290	1060
½	1780	1430	1190	980
¾	1440	1160	960	790
1	1320	1060	880	720
1¼	1090	870	730	600
1½	990	790	660	540
2	850	680	570	460
2½	890	710	590	490
3	790	630	520	430
3½	730	580	480	400
4	680	540	450	370
5	610	490	400	330
6	590	470	390	320
8	520	410	340	280
10	490	390	330	270
12	480	380	320	260
in.	MPa			
⅛	17.72	14.21	11.86	9.72
¼	16.34	13.10	10.90	8.96
⅜	13.31	10.62	8.89	7.31
½	12.27	9.86	8.20	6.76
¾	9.93	8.00	6.62	5.45
1	9.10	7.31	6.07	4.96
1¼	7.52	6.00	5.03	4.14
1½	6.83	4.96	4.55	3.72
2	5.86	4.69	3.93	3.17
2½	6.14	4.90	4.07	3.38
3	5.45	4.34	3.59	2.96
3½	5.03	4.00	3.31	2.76
4	4.69	3.72	3.10	2.55
5	4.21	3.38	2.76	2.28
6	4.07	3.24	2.69	2.21
8	3.59	2.83	2.34	1.93
10	3.38	2.69	2.28	1.86
12	3.31	2.62	2.21	1.79

[A] The fiber stresses used to derive these test pressures are as follows:

	psi	MPa
PVC1120	4200	29.0
PVC1220	4200	29.0
PVC2120	4200	29.0
PVC2116	3360	23.2
PVC2112	2800	19.3
PVC2110	2300	15.9

TABLE 5 Sustained Pressure Test Conditions for Water at 73°F (23°C) for PVC Plastic Pipe, Schedule 120

Nominal Pipe Size	PVC1120 PVC1220 PVC2120	PVC2116	PVC2112	PVC2110
in.	psi			
½	2130	1710	1420	1170
¾	1620	1300	1080	890
1	1510	1200	1000	830
1¼	1250	1000	830	680
1½	1130	900	750	620
2	990	790	660	540
2½	980	780	650	540
3	930	750	620	510
3½	810	640	540	440
4	900	720	600	490
5	830	660	550	450
6	780	620	520	430
8	760	610	510	420
10	770	620	510	420
12	710	570	480	390
in.	MPa			
½	14.69	11.79	9.79	8.07
¾	11.17	8.96	7.45	6.14
1	10.41	8.27	6.89	5.72
1¼	8.62	6.89	5.72	4.69
1½	7.79	6.21	5.17	4.27
2	6.83	5.45	4.55	3.72
2½	6.76	5.38	4.48	3.72
3	6.41	5.17	4.27	3.52
3½	5.58	4.41	3.72	3.03
4	6.21	4.96	4.14	3.38
5	5.72	4.55	3.79	3.10
6	5.38	4.27	3.59	2.96
8	5.24	4.21	3.52	2.90
10	5.31	4.27	3.52	2.90
12	4.90	3.93	3.31	2.69

[A] The fiber stresses used to derive these test pressures are as follows:

	psi	MPa
PVC1120	4200	29.0
PVC1220	4200	29.0
PVC2120	4200	29.0
PVC2116	3360	23.2
PVC2112	2800	19.3
PVC2110	2300	15.9

TABLE 6 Burst Pressure Requirements for Water at 73°F (23°C) for PVC Plastic Pipe, Schedules 40, 80, and 120

Nominal Pipe Size	Minimum Burst Pressure[A]					
	Schedule 40		Schedule 80		Schedule 120	
	PVC1120 PVC1220 PVC2120	PVC2112 PVC2116 PVC2110	PVC1120 PVC1220 PVC2120	PVC2112 PVC2116 PVC2110	PVC1120 PVC1220 PVC2120	PVC2112 PVC2116 PVC2110
in.	psi					
⅛	2580	2020	3920	3060	...	...
¼	2490	1950	3620	2830	...	...
⅜	1990	1560	2940	2300	...	...
½	1910	1490	2720	2120	3250	2540
¾	1540	1210	2200	1720	2470	1930
1	1440	1130	2020	1580	2300	1790
1¼	1180	920	1660	1300	1900	1490
1½	1060	830	1510	1180	1720	1340
2	890	690	1290	1010	1510	1180
2½	970	760	1360	1060	1490	1170
3	840	660	1200	940	1420	1110
3½	770	600	1110	860	1230	960
4	710	560	1040	810	1380	1080
5	620	390	930	720	1260	990
6	560	440	890	700	1190	930
8	500	390	790	620	1160	910
10	450	350	750	580	1170	920
12	420	330	730	570	1090	850
in.	MPa					
⅛	17.79	13.93	27.03	21.10	...	...
¼	17.17	13.45	24.96	19.52	...	...
⅜	13.72	10.76	20.27	15.86	...	...
½	13.17	10.27	18.76	14.62	22.41	17.52
¾	10.62	8.34	15.17	11.86	17.03	13.31
1	9.93	7.79	13.93	10.89	15.86	12.34
1¼	8.14	6.34	11.45	8.96	13.10	10.27
1½	7.31	5.72	10.41	8.14	11.86	9.24
2	6.14	4.76	8.89	6.96	10.41	8.14
2½	6.69	5.24	9.38	7.31	10.27	8.07
3	5.79	4.55	8.27	6.48	9.79	7.65
3½	5.31	4.14	7.65	5.93	8.48	6.62
4	4.90	3.86	7.17	5.58	9.51	7.45
5	4.27	2.69	6.41	4.96	8.69	6.83
6	3.86	3.03	6.14	4.83	8.20	6.41
8	3.45	2.69	5.45	4.27	8.00	6.27
10	3.10	2.41	5.17	4.00	8.07	6.34
12	2.90	2.28	5.03	3.93	7.52	5.86

[A] The fiber stresses used to derive these test pressures are as follows:

	psi	MPa
PVC1120	6400	44.1
PVC1220	6400	44.1
PVC2120	6400	44.1
PVC2116	5000	34.5
PVC2112	5000	34.5
PVC2110	5000	34.5

APPENDIX

(Nonmandatory Information)

X1. SOURCE OF HYDROSTATIC DESIGN STRESSES

X1.1 The hydrostatic design stresses recommended by the Plastics Pipe Institute are used to pressure rate PVC plastic pipe. These hydrostatic design stresses are 2000 psi (14 MPa), 1600 psi (11.2 MPa), 1250 psi (8.7 MPa, and 1000 psi (7 MPa) for water at 73°F (23°C). These hydrostatic design stresses apply only to pipe meeting all the requirements of this specification.

X1.2 Six PVC pipe materials are included based on the requirements of Specification D 1784 and the PPI-recommended hydrostatic design stresses as follows:

X1.2.1 Type I, Grade 1 (12454-B), with a hydrostatic design stress of 2000 psi (14 MPa), designated as PVC1120.

X1.2.2 Type I, Grade 2 (12454-C), with a hydrostatic design stress of 2000 psi (14 MPa), designated as PVC1220.

X1.2.3 Type II, Grade 1 (14333-D), with a hydrostatic design stress of 2000 psi (14 MPa), designated as PVC2120.

X1.2.4 Type II, Grade 1 (14333-D), with a hydrostatic design stress of 1600 psi (11.2 MPa), designated as PVC2116.

X1.2.5 Type II, Grade 1 (14333-D), with a hydrostatic design stress of 1250 psi (8.7 MPa), designated as PVC2112.

X1.2.6 Type II, Grade 1 (14333-D), with a hydrostatic design stress of 1000 psi (7.0 MPa), designated as PVC2110.

X1.3 The standard method for obtaining hydrostatic basis for thermoplastic pipe materials is Method D 2837. Additional information regarding the method of test and other criteria used in developing these hydrostatic design stresses may be obtained from the Plastics Pipe Institute, a division of The Society of the Plastics Industry, 355 Lexington Ave., New York, NY 10017. These hydrostatic design stresses may not be suitable for materials that show a wide departure from a straight-line plot of log stress versus log time to failure. All the data available to date on PVC pipe materials made in the United States exhibit a straight-line plot under these plotting conditions.

X1.4 The pipe is rated for use with water at 73°F (23°C) at the maximum internal pressures shown in Tables X1.1, X1.2, and X1.3. Lower pressure ratings than those calculated in accordance with 3.4 may be recommended, at the option of the pipe manufacturer, in which case the SDR shall be included in the marking. Experience of the industry indicates that PVC plastic pipe meeting the requirements of this specification gives satisfactory service under normal conditions for a long period at these pressure ratings. The sustained pressure requirements are related to these ratings through the slopes of the strength-time plots of these materials in pipe form.

X1.5 The hydrostatic design stresses recommended by the Plastics Pipe Institute are based on tests made on pipe ranging in size from ½ to 2½ in. (12.5 to 63.5 mm).

TABLE X1.1 Water Pressure Ratings at 73°F (23°C) for Schedule 40 PVC Plastic Pipe

Nominal Pipe Size	Pressure Ratings[a]			
	PVC1120[b] PVC1220 PVC2120	PVC2116	PVC2112[b]	PVC2110[b]
in.	psi			
⅛	810	650	500	400
¼	780	620	490	390
⅜	620	500	390	310
½	600	480	370	300
¾	480	390	300	240
1	450	360	280	220
1¼	370	290	230	180
1½	330	260	210	170
2	280	220	170	140
2½	300	240	190	150
3	260	210	160	130
3½	240	190	150	120
4	220	180	140	110
5	190	160	120	100
6	180	140	110	90
8	160	120	100	80
10	140	110	90	70
12	130	110	80	70
in.	MPa (bar)[c]			
⅛	5.58 (56)	4.48 (45)	3.45 (34)	2.76 (28)
¼	5.38 (54)	4.27 (43)	3.38 (33)	2.69 (27)
⅜	4.27 (43)	3.45 (34)	2.69 (27)	2.14 (21)
½	4.14 (41)	3.31 (33)	2.55 (25)	2.07 (21)
¾	3.31 (33)	2.69 (27)	2.07 (21)	1.65 (16)
1	3.10 (31)	2.48 (25)	1.93 (19)	1.52 (15)
1¼	2.55 (25)	2.04 (20)	1.59 (16)	1.24 (12)
1½	2.28 (23)	1.79 (18)	1.45 (14)	1.17 (12)
2	1.93 (19)	1.52 (15)	1.17 (12)	0.97 (9.7)
2½	2.07 (21)	1.65 (16)	1.31 (13)	1.03 (10)
3	1.79 (28)	1.45 (14)	1.10 (11)	0.90 (9.0)
3½	1.65 (16)	1.31 (13)	1.03 (10)	0.83 (8.3)
4	1.52 (15)	1.24 (12)	0.97 (9.7)	0.76 (7.6)
5	1.31 (13)	1.10 (11)	0.83 (8.3)	0.69 (6.9)
6	1.24 (12)	0.97 (9.7)	0.76 (7.6)	0.62 (6.2)
8	1.10 (11)	0.83 (8.3)	0.69 (6.9)	0.55 (5.5)
10	0.97 (9.7)	0.76 (7.6)	0.62 (6.2)	0.48 (4.8)
12	0.90 (9.0)	0.76 (7.6)	0.55 (5.5)	0.48 (4.8)

[a] These pressure ratings apply only to unthreaded pipe. The industry does not recommend threading PVC plastic pipe in Schedule 40 dimensions in nominal pipe sizes 6 in. (150 mm) and smaller.
[b] See Appendix for code designation.
[c] 1 bar = 14.504 psi.

TABLE X1.2 Water Pressure Ratings at 73°F (23°C) for Schedule 80 PVC Plastic Pipe

psi

Nominal Pipe Size, in.	PVC1120, PVC1220, PVC2120		PVC2116		PVC2112		PVC2110	
	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded
⅛	1230	610	980	490	770	380	610	310
¼	1130	570	900	450	710	350	570	280
⅜	920	460	730	370	570	290	460	230
½	850	420	680	340	530	260	420	210
¾	690	340	550	280	430	210	340	170
1	630	320	500	250	390	200	320	160
1¼	520	260	420	210	320	160	260	130
1½	470	240	380	190	290	150	240	120
2	400	200	320	160	250	130	200	100
2½	420	210	340	170	260	130	210	110
3	370	190	300	150	230	120	190	90
3½	350	170	280	140	220	110	170	90
4	320	160	260	130	200	100	160	80
5	290	140	230	120	180	90	140	70
6	280	140	220	110	170	90	140	70
8	250	120	200	100	150	80	120	60
10	230	120	190	90	150	70	120	60
12	230	110	180	90	140	70	110	60

MPa (bar)

Nominal Pipe Size, in.	PVC1120, PVC1220, PVC2120		PVC2116		PVC2112		PVC2110	
	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded
⅛	8.48 (85)	4.21 (42)	6.76 (68)	3.38 (39)	5.31 (53)	2.62 (26)	4.21 (42)	2.14 (21)
¼	7.79 (80)	3.93 (39)	6.21 (62)	3.10 (31)	4.90 (49)	2.41 (24)	3.93 (40)	1.93 (19)
⅜	6.34 (63)	3.17 (32)	5.03 (50)	2.55 (25)	3.93 (39)	2.00 (20)	3.17 (32)	1.59 (16)
½	5.86 (59)	2.90 (29)	4.69 (47)	2.34 (23)	3.65 (36)	1.79 (18)	2.90 (29)	1.45 (14)
¾	4.76 (48)	2.34 (23)	3.79 (38)	1.93 (19)	2.96 (29)	1.45 (14)	2.34 (23)	1.17 (12)
1	4.34 (43)	2.21 (22)	3.45 (34)	1.72 (17)	2.69 (27)	1.38 (13)	2.21 (22)	1.10 (11)
1¼	3.59 (36)	1.79 (18)	2.90 (29)	1.45 (14)	2.21 (22)	1.10 (11)	1.79 (18)	0.90 (9.0)
1½	3.24 (32)	1.65 (16)	2.62 (26)	1.31 (13)	2.0 (20)	1.03 (10)	1.65 (16)	0.83 (8.3)
2	2.76 (28)	1.38 (14)	2.21 (22)	1.10 (11)	1.72 (17)	0.90 (9.0)	1.38 (14)	0.69 (6.9)
2½	2.90 (29)	1.45 (15)	2.34 (23)	1.17 (12)	1.79 (18)	0.90 (9.0)	1.45 (14)	0.76 (7.6)
3	2.55 (25)	1.31 (13)	2.07 (21)	1.03 (10)	1.59 (16)	0.83 (8.3)	1.31 (13)	0.62 (6.2)
3½	2.41 (24)	1.17 (12)	1.93 (19)	0.97 (9.7)	1.52 (15)	0.76 (7.6)	1.17 (12)	0.62 (6.2)
4	2.21 (22)	1.10 (11)	1.79 (18)	0.90 (9.0)	1.38 (14)	0.69 (6.9)	1.10 (11)	0.55 (5.5)
5	2.00 (20)	0.97 (9.7)	1.59 (16)	0.83 (8.3)	1.24 (12)	0.62 (6.2)	0.97 (9.7)	0.48 (4.8)
6	1.93 (19)	0.97 (9.7)	1.52 (15)	0.76 (7.6)	1.17 (11)	0.62 (6.2)	0.97 (9.7)	0.48 (4.8)
8	1.72 (17)	0.83 (8.3)	1.38 (14)	0.69 (6.9)	1.03 (10)	0.55 (5.5)	0.83 (8.3)	0.41 (4.1)
10	1.59 (16)	0.83 (8.3)	1.31 (13)	0.62 (6.2)	1.03 (10)	0.48 (4.8)	0.83 (8.3)	0.41 (4.1)
12	1.59 (16)	0.76 (7.6)	1.24 (12)	0.62 (6.2)	0.97 (9.7)	0.48 (4.8)	0.76 (7.6)	0.41 (4.1)

TABLE X1.3 Water Pressure Ratings at 73°F (23°C) for Schedule 120 PVC Plastic Pipe

psi

Nominal Pipe Size, in.	PVC1120, PVC1220, PVC2120		PVC2116		PVC2112		PVC2110	
	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded
½	1010	510	810	410	630	320	510	250
¾	770	390	620	310	480	240	390	190
1	720	360	570	290	450	220	360	180
1¼	600	300	480	240	370	190	300	150
1½	540	270	430	210	340	170	270	130
2	470	240	380	190	290	150	240	120
2½	470	230	370	190	290	150	230	120
3	440	220	360	180	280	140	220	110
3½	380	190	310	150	240	120	190	100
4	430	220	340	170	270	130	220	110
5	400	200	320	160	250	120	200	100
6	370	190	300	150	230	120	190	90
8	380	180	290	140	230	110	180	90
10	370	180	290	140	230	110	180	90
12	340	170	270	140	210	110	170	80

MPa (bar)

Nominal Pipe Size, in.	PVC1120, PVC1220, PVC2120		PVC2116		PVC2112		PVC2110	
	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded
½	6.96 (70)	3.52 (35)	5.58 (56)	2.83 (28)	4.34 (43)	2.21 (22)	3.52 (35)	1.72 (17)
¾	5.31 (53)	2.69 (27)	4.27 (43)	2.14 (21)	3.31 (33)	1.65 (16)	2.69 (27)	1.31 (13)
1	4.96 (50)	2.48 (25)	3.93 (39)	2.00 (20)	3.10 (31)	1.52 (15)	2.48 (25)	1.24 (12)
1¼	4.14 (41)	2.07 (21)	3.31 (33)	1.65 (16)	2.55 (25)	1.31 (13)	2.07 (21)	1.03 (10)
1½	3.72 (37)	1.86 (19)	2.96 (30)	1.45 (14)	2.34 (23)	1.17 (12)	1.86 (18)	0.90 (9.0)
2	3.24 (32)	1.65 (17)	2.62 (26)	1.31 (13)	2.00 (20)	1.03 (10)	1.65 (16)	0.83 (8.3)
2½	3.24 (32)	1.59 (16)	2.55 (25)	1.31 (13)	2.00 (20)	1.03 (10)	1.59 (16)	0.83 (8.3)
3	3.03 (30)	1.52 (15)	2.48 (24)	1.24 (12)	1.93 (19)	0.97 (9.7)	1.52 (15)	0.76 (7.6)
3½	2.62 (26)	1.31 (13)	2.14 (21)	1.03 (10)	1.65 (16)	0.83 (8.3)	1.31 (13)	0.69 (6.9)
4	2.96 (29)	1.52 (15)	2.34 (23)	1.17 (12)	1.86 (18)	0.90 (9.0)	1.52 (15)	0.76 (7.6)
5	2.76 (27)	1.38 (14)	2.21 (22)	1.10 (11)	1.72 (17)	0.83 (8.3)	1.38 (14)	0.69 (6.9)
6	2.55 (25)	1.31 (13)	2.07 (21)	1.03 (10)	1.59 (16)	0.83 (8.3)	1.31 (13)	0.62 (6.2)
8	2.62 (26)	1.24 (12)	2.00 (20)	0.97 (9.7)	1.59 (16)	0.76 (7.6)	1.24 (12)	0.62 (6.2)
10	2.55 (25)	1.24 (12)	2.00 (20)	0.97 (9.7)	1.59 (16)	0.76 (7.6)	1.24 (12)	0.62 (6.2)
12	2.34 (23)	1.17 (11)	1.86 (18)	0.97 (9.7)	1.45 (14)	0.76 (7.6)	1.17 (11)	0.55 (5.5)

Designation: D 2216

Standard Method for

LABORATORY DETERMINATION OF WATER (MOISTURE) CONTENT OF SOIL, ROCK, AND SOIL-AGGREGATE MIXTURES[1]

1. Scope

1.1 This method covers the laboratory determination of the water (moisture) content of soil, rock, and soil-aggregate mixtures by weight. For simplicity, the word "material" hereinafter refers to either soil, rock, or soil-aggregate mixtures, whichever is most applicable.

1.2 The water content of a material is defined as the ratio, expressed as a percentage, of the mass of "pore" or "free" water in a given mass of material to the mass of the solid material particles.

1.3 This method does not give true representative results for: materials containing significant amounts of halloysite, montmorillonite, or gypsum minerals; highly organic soils; or, materials in which the pore water contains dissolved solids (such as salt in the case of marine deposits). For a material of the previously mentioned types, a modified method of testing or data calculation may be established to give results consistent with the purpose of the test.

2. Summary of Method

2.1 The practical application in determining the water content of a material is to determine the mass of water removed by drying the moist material (test specimen) to a constant mass in a drying oven controlled at 110 ± 5°C and to use this value as the mass of water in the test specimen. The mass of material remaining after oven-drying is used as the mass of the solid particles.

3. Significance and Use

3.1 For many soil types, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and an index property.

3.2 The water content of a soil is used in almost every equation expressing the phase relationships of air, water, and solids in a given volume of material.

3.3 In fine-grained (cohesive) soils, the consistency of a given soil type depends on its water content. The water content of a soil, along with its liquid and plastic limit, is used to express its relative consistency or liquidity index.

3.4 The term "water" as used in geotechnical engineering, is typically assumed to be "pore" or "free" water and not that which is hydrated to the mineral surfaces. Therefore, the water content of materials containing significant amounts of hydrated water at in-situ temperatures or less than 110°C can be misleading.

3.5 The term "solid particles" as used in geotechnical engineering, is typically assumed to mean naturally occurring mineral particles that are not readily soluble in water. Therefore, the water content of materials containing extraneous matter (such as cement, etc), water-soluble matter (such as salt) and highly organic

[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.
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matter typically require special treatment or a qualified definition of water content.

4. Apparatus

4.1 *Drying Oven*, thermostatically-controlled, preferably of the forced-draft type, and maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber.

4.2 *Balances*, having a precision (repeatability) of ±0.01 g for specimens having a mass of 200 g or less, ±0.1 g for specimens having a mass of between 200 and 1000 g, or ± 1 g for specimens having a mass greater than 1000 g.

4.3 *Specimen Containers*—Suitable containers made of material resistant to corrosion and a change in mass upon repeated heating, cooling, and cleaning. Containers with close-fitting lids shall be used for testing specimens having a mass of less than about 200 g; while for specimens having a mass greater than about 200 g, containers without lids may be used (Note 1). One container is needed for each water content determination.

NOTE 1—The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing.

4.4 *Desiccator*—A desiccator of suitable size (a convenient size is 200 to 250-mm diameter) containing a hydrous silica gel. This equipment is only recommended for use when containers having close-fitting lids are not used. See 7.4.1.

5. Samples

5.1 Keep the samples that are stored prior to testing in noncorrodible airtight containers at a temperature between approximately 3 and 30°C and in an area that prevents direct contact with sunlight.

5.2 The water content determination should be done as soon as practicable after sampling, especially if potentially corrodible containers (such as steel thin-walled tubes, paint cans, etc.) or sample bags are used.

6. Test Specimen

6.1 For water contents being determined in conjunction with another ASTM method, the method of specimen selection specified in that method controls.

6.2 The manner in which the test specimen is selected and its required mass is basically dependent on the purpose (application) of the test, type of material being tested, and the type of sample (specimen from another test, bag, tube, split-barrel, etc.). In all cases, however, a representative portion of the total sample shall be selected. If a layered soil or more than one soil type is encountered, select an average portion or individual portions or both, and note which portion(s) was tested in the report of the results.

6.2.1 For bulk samples, select the test specimen from the material after it has been thoroughly mixed. The mass of moist material selected shall be in accordance with the following table:

Sieve Retaining More Than About 10 % of Sample	Recommended Minimum Mass of Moist Specimen, g
2.0 mm (No. 10) sieve	100 to 200
4.75 mm (No. 4) sieve	300 to 500
19 mm	500 to 1000
38 mm	1500 to 3000
76 mm	5000 to 10 000

6.2.2 For small (jar) samples, select a representative portion in accordance with the following procedure:

6.2.2.1 For cohesionless soils, thoroughly mix the material, then select a test specimen having a mass of moist material in accordance with the table in 6.2.1. See Note 2.

6.2.2.2 For cohesive soils, remove about 3 mm of material from the exposed periphery of the sample and slice it in half (to check if the material is layered) prior to selecting the test specimen. If the soil is layered see 6.2. The mass of moist material selected should not be less than 25 g or should be in accordance with the table in 6.2.1 if coarse-grained particles are noted. (Note 2).

6.3 Using a test specimen smaller than the minimum mass indicated previously requires discretion, though it may be adequate for the purpose of the test. A specimen having a mass less than the previously indicated value shall be noted in the report of the results.

NOTE 2—In many cases, when working with a small sample containing a relatively large coarse-grained particle, it is appropriate not to include this particle in the test specimen. If this occurs, it should be noted in the report of the results.

7. Procedure

7.1 Select representative test specimens in accordance with Section 6.

7.2 Place the moist specimen in a clean, dry container of known mass (Note 3), set the lid securely in position, and determine the mass of the container and moist material using an appropriate balance (4.2). Record these values.

7.3 Remove the lid and place the container with moist material in a drying oven maintained at 110 ± 5°C and dry to a constant mass (Notes 4, 5, and 6).

NOTE 3— To assist in the oven-drying of large test specimens, they should be placed in containers having a large surface area (such as pans) and the material broken up into smaller aggregations.

NOTE 4—The time required to obtain constant mass will vary depending on the type of material, size of specimen, oven type and capacity, and other factors. The influence of these factors generally can be established by good judgment, and experience with the material being tested and the apparatus being used. In most cases, drying a test specimen over night (about 16 h) is sufficient. In cases where there is doubt concerning the adequacy of drying, drying should be continued until the mass after two successive periods (greater than ½ h) of drying indicate an insignificant change (less than about 0.1 %). Specimens of sand may often be dried to constant mass in a period of about 4 h, when a forced-draft oven is used.

NOTE 5—Oven-drying at 110 ± 5°C does not always result in water content values related to the intended use or the basic definition especially for materials containing gypsum or other minerals having significant amounts of hydrated water or for soil containing a significant amount of organic material. In many cases, and depending on the intended use for these types of material, it might be more applicable to maintain the drying oven at 60 ± 5°C or use a vacuum desiccator at a vacuum of approximately 133 Pa (10 mm Hg) and at a temperature ranging between 23 and 60°C for drying. If either of these drying methods are used, it should be noted in the report of the results.

NOTE 6—Since some dry materials may absorb moisture from moist specimens, dried specimens should be removed before placing moist specimens in the oven. However, this requirement is not applicable if the previously dried specimens will remain in the drying oven for an additional time period of about 16 h.

7.4 After the material has dried to constant mass remove the container from the oven and replace the lid. Allow the material and container to cool to room temperature or until the container can be handled comfortably with bare hands and the operation of the balance will not be affected by convection currents. Determine the mass of the container and oven-dried material using the same balance as used in 7.2. Record this value.

7.4.1 If the container does not have a lid, weigh the container and material right after their temperatures are such that the operation of the balance will not be affected by convection currents or after cooling in a desiccator.

NOTE 7—Cooling in a desiccator is recommended since it prevents absorption of moisture from the atmosphere during cooling.

8. Calculation

8.1 Calculate the water content of the material as follows:

$$w = [(W_1 - W_2)/(W_2 - W_c)] \times 100 = \frac{W_w}{W_s} \times 100$$

where:

- w = water content, %,
- W_1 = mass of container and moist specimen, g,
- W_2 = mass of container and oven-dried specimen, g,
- W_c = mass of container, g,
- W_w = mass of water, g, and
- W_s = mass of solid particles, g.

9. Report

9.1 The report (data sheet) shall include the following:

9.1.1 Identification of the sample (material) being tested, by boring number, sample number, test number, etc.

9.1.2 Water content of the specimen to the nearest 0.1 % or 1 %, depending on the purpose of the test.

9.1.3 Indication of test specimen having a mass less than the minimum indicated in Section 6.

9.1.4 Indication of test specimen containing more than one soil type (layered, etc).

9.1.5 Indication of the method of drying if different from oven-drying at 110 ± 5°C.

9.1.6 Indication of any material (size and amount) excluded from the test specimen.

Standard Method for
PARTICLE-SIZE ANALYSIS OF SOILS¹

1. Scope

1.1 This method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 μm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 μm is determined by a sedimentation process, using a hydrometer to secure the necessary data (Notes 1 and 2).

NOTE 1—Separation may be made on the No. 4 (4.75-mm), No. 40 (425-μm), or No. 200 (75-μm) sieve instead of the No. 10. For whatever sieve used, the size shall be indicated in the report.

NOTE 2—Two types of dispersion devices are provided: (1) a high-speed mechanical stirrer, and (2) air dispersion. Extensive investigations indicate that air-dispersion devices produce a more positive dispersion of plastic soils below the 20-μm size and appreciably less degradation on all sizes when used with sandy soils. Because of the definite advantages favoring air dispersion, its use is recommended. The results from the two types of devices differ in magnitude, depending upon soil type, leading to marked differences in particle size distribution, especially for sizes finer than 20 μm.

2. Applicable Documents

2.1 *ASTM Standards:*

D 421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants²

E 11 Specification for Wire-Cloth Sieves for Testing Purposes³

E 100 Specification for ASTM Hydrometers⁴

3. Apparatus

3.1 *Balances*—A balance sensitive to 0.01 g for weighing the material passing a No. 10 (2.00-mm) sieve, and a balance sensitive to 0.1 % of the mass of the sample to be weighed for weighing the material retained on a No. 10 sieve.

3.2 *Stirring Apparatus*—Either apparatus A or B may be used.

3.2.1 Apparatus A shall consist of a mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10 000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber, as shown in Fig. 1. The shaft shall be of such length that the stirring paddle will operate not less than ¾ in. (19.0 mm) nor more than 1½ in. (38.1 mm) above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be provided to hold the sample while it is being dispersed.

3.2.2 Apparatus B shall consist of an air-jet dispersion cup⁵ (Note 3) conforming to the general details shown in Fig. 3 (Notes 4 and 5).

NOTE 3—The amount of air required by an air-jet dispersion cup is of the order of 2 ft³/min; some small air compressors are not capable of supplying sufficient air to operate a cup.

NOTE 4—Another air-type dispersion device, known as a dispersion tube, developed by Chu and Davidson at Iowa State College, has been shown to give

results equivalent to those secured by the air-jet dispersion cups. When it is used, soaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transferring the slurry. When the air-dispersion tube is used, it shall be so indicated in the report.

NOTE 5—Water may condense in air lines when not in use. This water must be removed, either by using a water trap on the air line, or by blowing the water out of the line before using any of the air for dispersion purposes.

3.3 *Hydrometer*—An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per litre of suspension, and conforming to the requirements for hydrometers 151H or 152H in Specifications E 100. Dimensions of both hydrometers are the same, the scale being the only item of difference.

3.4 *Sedimentation Cylinder*—A glass cylinder essentially 18 in. (457 mm) in height and 2½ in. (63.5 mm) in diameter, and marked for a volume of 1000 mL. The inside diameter shall be such that the 1000-mL mark is 36 ± 2 cm from the bottom on the inside.

3.5 *Thermometer*—A thermometer accurate to 1°F (0.5°C).

3.6 *Sieves*—A series of sieves, of square-mesh woven-wire cloth, conforming to the requirements of Specification E 11. A full set of sieves includes the following (Note 6):

3-in. (75-mm)	No. 10 (2.00-mm)
2-in. (50-mm)	No. 20 (850-μm)
1½-in. (37.5-mm)	No. 40 (425-μm)
1-in. (25.0-mm)	No. 60 (250-μm)
¾-in. (19.0-mm)	No. 140 (106-μm)
⅜-in. (9.5-mm)	No. 200 (75-μm)
No. 4 (4.75-mm)	

NOTE 6—A set of sieves giving uniform spacing of points for the graph, as required in Section 17, may be used if desired. This set consists of the following sieves:

3-in. (75-mm)	No. 16 (1.18-mm)
1½-in. (37.5-mm)	No. 30 (600-μm)
¾-in. (19.0-mm)	No. 50 (300-μm)
⅜-in. (9.5-mm)	No. 100 (150-μm)
No. 4 (4.75-mm)	No. 200 (75-μm)
No. 8 (2.36-mm)	

3.7 *Water Bath or Constant-Temperature Room*—A water bath or constant-temperature room for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory water tank is an insulated tank that maintains the temperature of the suspension at a convenient constant temperature at or near 68°F (20°C). Such a device is illustrated in Fig. 4. In cases where the work is performed in a room at an automatically controlled constant

temperature, the water bath is not necessary.

3.8 *Beaker*—A beaker of 250-mL capacity.

3.9 *Timing Device*—A watch or clock with a second hand.

4. Dispersing Agent

4.1 A solution of sodium hexametaphosphate (sometimes called sodium metaphosphate) shall be used in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate/litre of solution (Note 7).

NOTE 7—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action. Solutions should be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate. Bottles containing solutions should have the date of preparation marked on them.

4.2 All water used shall be either distilled or demineralized water. The water for a hydrometer test shall be brought to the temperature that is expected to prevail during the hydrometer test. For example, if the sedimentation cylinder is to be placed in the water bath, the distilled or demineralized water to be used shall be brought to the temperature of the controlled water bath; or, if the sedimentation cylinder is used in a room with controlled temperature, the water for the test shall be at the temperature of the room. The basic temperature for the hydrometer test is 68°F (20°C). Small variations of temperature do not introduce differences that are of practical significance and do not prevent the use of corrections derived as prescribed.

5. Test Sample

5.1 Prepare the test sample for mechanical analysis as outlined in Practice D 421. During the preparation procedure the sample is divided into two portions. One portion contains only particles retained on the No. 10 (2.00-mm) sieve while the other portion contains only particles passing the No. 10 sieve. The mass of air-dried soil selected for purpose of tests, as prescribed in Practice D 421, shall be sufficient to yield quantities for mechanical analysis as follows:

5.1.1 The size of the portion retained on the No. 10 sieve shall depend on the maximum size of particle, according to the following schedule:

Nominal Diameter of Largest Particles, in. (mm)	Approximate Minimum Mass of Portion, g
⅜ (9.5)	500
¾ (19.0)	1000

Nominal Diameter of Largest Particles, in. (mm)	Approximate Minimum Mass of Portion, g
1 (25.4)	2000
1½ (38.1)	3000
2 (50.8)	4000
3 (76.2)	5000

5.1.2 The size of the portion passing the No. 10 sieve shall be approximately 115 g for sandy soils and approximately 65 g for silt and clay soils.

5.2 Provision is made in Section 5 of Practice D 421 for weighing of the air-dry soil selected for purpose of tests, the separation of the soil on the No. 10 sieve by dry-sieving and washing, and the weighing of the washed and dried fraction retained on the No. 10 sieve. From these two masses the percentages retained and passing the No. 10 sieve can be calculated in accordance with 12.1.

NOTE 8—A check on the mass values and the thoroughness of pulverization of the clods may be secured by weighing the portion passing the No. 10 sieve and adding this value to the mass of the washed and oven-dried portion retained on the No. 10 sieve.

SIEVE ANALYSIS OF PORTION RETAINED ON NO. 10 (2.00-mm) SIEVE

6. Procedure

6.1 Separate the portion retained on the No. 10 (2.00-mm) sieve into a series of fractions using the 3-in. (75-mm), 2-in. (50-mm), 1½-in. (37.5-mm), 1-in. (25.0-mm), ¾-in. (19.0-mm), ⅜-in. (9.5-mm), No. 4 (4.75-mm), and No. 10 sieves, or as many as may be needed depending on the sample, or upon the specifications for the material under test.

6.2 Conduct the sieving operation by means of a lateral and vertical motion of the sieve, accompanied by a jarring action in order to keep the sample moving continuously over the surface of the sieve. In no case turn or manipulate fragments in the sample through the sieve by hand. Continue sieving until not more than 1 mass % of the residue on a sieve passes that sieve during 1 min of sieving. When mechanical sieving is used, test the thoroughness of sieving by using the hand method of sieving as described above.

6.3 Determine the mass of each fraction on a balance conforming to the requirements of 3.1. At the end of weighing, the sum of the masses retained on all the sieves used should equal closely the original mass of the quantity sieved.

HYDROMETER AND SIEVE ANALYSIS OF PORTION PASSING THE NO. 10 (2.00-mm) SIEVE

7. Determination of Composite Correction for Hydrometer Reading

7.1 Equations for percentages of soil remaining in suspension, as given in 14.3, are based on the use of distilled or demineralized water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.

7.1.1 Both soil hydrometers are calibrated at 68°F (20°C), and variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

7.1.2 Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.

7.1.3 The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.

7.2 For convenience, a graph or table of composite corrections for a series of 1° temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight-line relationship between the two observed values.

7.3 Prepare 1000 mL of liquid composed of distilled or demineralized water and dispersing agent in the same proportion as will prevail in the sedimentation (hydrometer) test. Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used. When the temperature of the liquid becomes constant, insert the hydrometer, and, after a short interval to permit the hydrometer to come to the temperature of the liquid, read the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151H the composite correction is the difference between this reading and one; for hy-

drometer 152H it is the difference between the reading and zero. Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before.

8. Hygroscopic Moisture

8.1 When the sample is weighed for the hydrometer test, weigh out an auxiliary portion of from 10 to 15 g in a small metal or glass container, dry the sample to a constant mass in an oven at 230 ± 9°F (110 ± 5°C), and weigh again. Record the masses.

9. Dispersion of Soil Sample

9.1 When the soil is mostly of the clay and silt sizes, weigh out a sample of air-dry soil of approximately 50 g. When the soil is mostly sand the sample should be approximately 100 g.

9.2 Place the sample in the 250-mL beaker and cover with 125 mL of sodium hexametaphosphate solution (40 g/L). Stir until the soil is thoroughly wetted. Allow to soak for at least 16 h.

9.3 At the end of the soaking period, disperse the sample further, using either stirring apparatus A or B. If stirring apparatus A is used, transfer the soil - water slurry from the beaker into the special dispersion cup shown in Fig. 2, washing any residue from the beaker into the cup with distilled or demineralized water (Note 9). Add distilled or demineralized water, if necessary, so that the cup is more than half full. Stir for a period of 1 min.

NOTE 9—A large size syringe is a convenient device for handling the water in the washing operation. Other devices include the wash-water bottle and a hose with nozzle connected to a pressurized distilled water tank.

9.4 If stirring apparatus B (Fig. 3) is used, remove the cover cap and connect the cup to a compressed air supply by means of a rubber hose. A air gage must be on the line between the cup and the control valve. Open the control valve so that the gage indicates 1 psi (7 kPa) pressure (Note 10). Transfer the soil - water slurry from the beaker to the air-jet dispersion cup by washing with distilled or demineralized water. Add distilled or demineralized water, if necessary, so that the total volume in the cup is 250 mL, but no more.

NOTE 10—The initial air pressure of 1 psi is required to prevent the soil - water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup.

9.5 Place the cover cap on the cup and open the air control valve until the gage pressure is 20 psi (140 kPa). Disperse the soil according to the following schedule:

Plasticity Index	Dispersion Period, min
Under 5	5
6 to 20	10
Over 20	15

Soils containing large percentages of mica need be dispersed for only 1 min. After the dispersion period, reduce the gage pressure to 1 psi preparatory to transfer of soil - water slurry to the sedimentation cylinder.

10. Hydrometer Test

10.1 Immediately after dispersion, transfer the soil - water slurry to the glass sedimentation cylinder, and add distilled or demineralized water until the total volume is 1000 mL.

10.2 Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 1 min to complete the agitation of the slurry (Note 11). At the end of 1 min set the cylinder in a convenient location and take hydrometer readings at the following intervals of time (measured from the beginning of sedimentation), or as many as may be needed, depending on the sample or the specification for the material under test: 2, 5, 15, 30, 60, 250, and 1440 min. If the controlled water bath is used, the sedimentation cylinder should be placed in the bath between the 2- and 5-min readings.

NOTE 11—The number of turns during this minute should be approximately 60, counting the turn upside down and back as two turns. Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorous shaking of the cylinder while it is in the inverted position.

10.3 When it is desired to take a hydrometer reading, carefully insert the hydrometer about 20 to 25 s before the reading is due to approximately the depth it will have when the reading is taken. As soon as the reading is taken, carefully remove the hydrometer and place it with a spinning motion in a graduate of clean distilled or demineralized water.

NOTE 12—It is important to remove the hydrometer immediately after each reading. Readings shall be taken at the top of the meniscus formed by the suspension around the stem, since it is not possible to secure readings at the bottom of the meniscus.

10.4 After each reading, take the temperature of the suspension by inserting the thermometer into the suspension.

11. Sieve Analysis

11.1 After taking the final hydrometer reading, transfer the suspension to a No. 200 (75-µm) sieve and wash with tap water until the wash water is clear. Transfer the material on the No. 200 sieve to a suitable container, dry in an oven at 230 ± 9°F (110 ± 5°C) and make a sieve analysis of the portion retained, using as many sieves as desired, or required for the material, or upon the specification of the material under test.

CALCULATIONS AND REPORT

12. Sieve Analysis Values for the Portion Coarser than the No. 10 (2.00-mm) Sieve

12.1 Calculate the percentage passing the No. 10 sieve by dividing the mass passing the No. 10 sieve by the mass of soil originally split on the No. 10 sieve, and multiplying the result by 100. To obtain the mass passing the No. 10 sieve, subtract the mass retained on the No. 10 sieve from the original mass.

12.2 To secure the total mass of soil passing the No. 4 (4.75-mm) sieve, add to the mass of the material passing the No. 10 sieve the mass of the fraction passing the No. 4 sieve and retained on the No. 10 sieve. To secure the total mass of soil passing the ⅜-in. (9.5-mm) sieve, add to the total mass of soil passing the No. 4 sieve, the mass of the fraction passing the ⅜-in. sieve and retained on the No. 4 sieve. For the remaining sieves, continue the calculations in the same manner.

12.3 To determine the total percentage passing for each sieve, divide the total mass passing (see 12.2) by the total mass of sample and multiply the result by 100.

13. Hygroscopic Moisture Correction Factor

13.1 The hygroscopic moisture correction factor is the ratio between the mass of the oven-dried sample and the air-dry mass before drying. It is a number less than one, except when there is no hygroscopic moisture.

14. Percentages of Soil in Suspension

14.1 Calculate the oven-dry mass of soil used in the hydrometer analysis by multiplying the air-dry mass by the hygroscopic moisture correc-

tion factor.

14.2 Calculate the mass of a total sample represented by the mass of soil used in the hydrometer test, by dividing the oven-dry mass used by the percentage passing the No. 10 (2.00-mm) sieve, and multiplying the result by 100. This value is the weight W in the equation for percentage remaining in suspension.

14.3 The percentage of soil remaining in suspension at the level at which the hydrometer is measuring the density of the suspension may be calculated as follows (Note 13): For hydrometer 151H:

$$P = [(100\,000/W) \times G/(G - G_1)](R - G_1)$$

NOTE 13—The bracketed portion of the equation for hydrometer 151H is constant for a series of readings and may be calculated first and then multiplied by the portion in the parentheses.

For hydrometer 152H:

$$P = (Ra/W) \times 100$$

where:
a = correction factor to be applied to the reading of hydrometer 152H. (Values shown on the scale are computed using a specific gravity of 2.65. Correction factors are given in Table 1),
P = percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the suspension,
R = hydrometer reading with composite correction applied (Section 7),
W = oven-dry mass of soil in a total test sample represented by mass of soil dispersed (see 14.2), g,
G = specific gravity of the soil particles, and
G_1 = specific gravity of the liquid in which soil particles are suspended. Use numerical value of one in both instances in the equation. In the first instance any possible variation produces no significant effect, and in the second instance, the composite correction for R is based on a value of one for G_1.

15. Diameter of Soil Particles

15.1 The diameter of a particle corresponding to the percentage indicated by a given hydrometer reading shall be calculated according to Stokes' law (Note 14), on the basis that a particle of this diameter was at the surface of the suspension at the beginning of sedimentation and had settled to the level at which the hydrometer is measuring the density of the suspension. Accord-

ing to Stokes' law:

$$D = \sqrt{[30n/980(G - G_1)] \times L/T}$$

where:

D = diameter of particle, mm,

n = coefficient of viscosity of the suspending medium (in this case water) in poises (varies with changes in temperature of the suspending medium),

L = distance from the surface of the suspension to the level at which the density of the suspension is being measured, cm. (For a given hydrometer and sedimentation cylinder, values vary according to the hydrometer readings. This distance is known as effective depth (Table 2)),

T = interval of time from beginning of sedimentation to the taking of the reading, min,

G = specific gravity of soil particles, and

G_1 = specific gravity (relative density) of suspending medium (value may be used as 1.000 for all practical purposes).

NOTE 14—Since Stokes' law considers the terminal velocity of a single sphere falling in an infinity of liquid, the sizes calculated represent the diameter of spheres that would fall at the same rate as the soil particles.

15.2 For convenience in calculations the above equation may be written as follows:

$$D = K\sqrt{L/T}$$

where:

K = constant depending on the temperature of the suspension and the specific gravity of the soil particles. Values of K for a range of temperatures and specific gravities are given in Table 3. The value of K does not change for a series of readings constituting a test, while values of L and T do vary.

15.3 Values of D may be computed with sufficient accuracy, using an ordinary 10-in. slide rule.

NOTE 15—The value of L is divided by T using the A- and B-scales, the square root being indicated on the D-scale. Without ascertaining the value of the square root it may be multiplied by K, using either the C- or CI-scale.

16. Sieve Analysis Values for Portion Finer than No. 10 (2.00-mm) Sieve

16.1 Calculation of percentages passing the various sieves used in sieving the portion of the sample from the hydrometer test involves several steps. The first step is to calculate the mass of the

fraction that would have been retained on the No. 10 sieve had it not been removed. This mass is equal to the total percentage retained on the No. 10 sieve (100 minus total percentage passing) times the mass of the total sample represented by the mass of soil used (as calculated in 14.2) and the result divided by 100.

16.2 Calculate next the total mass passing the No. 200 sieve. Add together the fractional masses retained on all the sieves, including the No. 10 sieve, and subtract this sum from the mass of the total sample (as calculated in 14.2).

16.3 Calculate next the total masses passing each of the other sieves, in a manner similar to that given in 12.2.

16.4 Calculate last the total percentages passing by dividing the total mass passing (as calculated in 16.3) by the total mass of sample (as calculated in 14.2), and multiply the result by 100.

17. Graph

17.1 When the hydrometer analysis is performed, a graph of the test results shall be made, plotting the diameters of the particles on a logarithmic scale as the abscissa and the percentages smaller than the corresponding diameters to an arithmetic scale as the ordinate. When the hydrometer analysis is not made on a portion of the soil, the preparation of the graph is optional, since values may be secured directly from tabulated data.

18. Report

18.1 The report shall include the following:

18.1.1 Maximum size of particles,

18.1.2 Percentage passing (or retained on) each sieve, which may be tabulated or presented by plotting on a graph (Note 16),

18.1.3 Description of sand and gravel particles:

18.1.3.1 Shape—rounded or angular,

18.1.3.2 Hardness—hard and durable, soft, or weathered and friable,

18.1.4 Specific gravity, if unusually high or low,

18.1.5 Any difficulty in dispersing the fraction passing the No. 10 (2.00-mm) sieve, indicating any change in type and amount of dispersing agent, and

18.1.6 The dispersion device used and the length of the dispersion period.

NOTE 16—This tabulation of graph represents the gradation of the sample tested. If particles larger than those contained in the sample were removed before testing, the report shall so state giving the amount and maximum size.

18.2 For materials tested for compliance with definite specifications, the fractions called for in such specifications shall be reported. The fractions smaller than the No. 10 sieve shall be read from the graph.

18.3 For materials for which compliance with definite specifications is not indicated and when the soil is composed almost entirely of particles passing the No. 4 (4.75-mm) sieve, the results from the graph may be reported as follows:

(1) Gravel, passing 3-in. and retained on No. 4 sieve ..... %

(2) Sand, passing No. 4 sieve and retained on No. 200 sieve ..... %

(a) Coarse sand, passing No. 4 sieve and retained on No. 10 sieve ..... %

(b) Medium sand, passing No. 10 sieve and retained on No. 40 sieve ..... %

(c) Fine sand, passing No. 40 sieve and retained on No. 200 sieve ..... %

(3) Silt size, 0.074 to 0.005 mm ..... %

(4) Clay size, smaller than 0.005 mm ..... %

Colloids, smaller than 0.001 mm ..... %

18.4 For materials for which compliance with definite specifications is not indicated and when the soil contains material retained on the No. 4 sieve sufficient to require a sieve analysis on that portion, the results may be reported as follows (Note 17):

SIEVE ANALYSIS

Sieve Size	Percentage Passing
3-in.	....
2-in.	....
1½-in.	....
1-in.	....
¾-in.	....
⅜-in.	....
No. 4 (4.75-mm)	....
No. 10 (2.00-mm)	....
No. 40 (425-μm)	....
No. 200 (75-μm)	....

HYDROMETER ANALYSIS

0.074 mm	....
0.005 mm	....
0.001 mm	....

NOTE 17—No. 8 (2.36-mm) and No. 50 (300-μm) sieves may be substituted for No. 10 and No. 40 sieves.

TABLE 1 Values of Correction Factor, a, for Different Specific Gravities of Soil Particles[A]

Specific Gravity	Correction Factor[A]
2.95	0.94
2.90	0.95
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.03
2.45	1.05

[A] For use in equation for percentage of soil remaining in suspension when using Hydrometer 152H.

TABLE 2 Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specified Sizes[A]

Hydrometer 151H		Hydrometer 152H	
Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm
1.000	16.3	0	16.3
1.001	16.0	1	16.1
1.002	15.8	2	16.0
1.003	15.5	3	15.8
1.004	15.2	4	15.6
1.005	15.0	5	15.5
1.006	14.7	6	15.3
1.007	14.4	7	15.2
1.008	14.2	8	15.0
1.009	13.9	9	14.8
1.010	13.7	10	14.7
1.011	13.4	11	14.5
1.012	13.1	12	14.3
1.013	12.9	13	14.2
1.014	12.6	14	14.0
1.015	12.3	15	13.8
1.016	12.1	16	13.7
1.017	11.8	17	13.5
1.018	11.5	18	13.3
1.019	11.3	19	13.2
1.020	11.0	20	13.0
1.021	10.7	21	12.9
1.022	10.5	22	12.7
1.023	10.2	23	12.5
1.024	10.0	24	12.4
1.025	9.7	25	12.2
1.026	9.4	26	12.0
1.027	9.2	27	11.9
1.028	8.9	28	11.7
1.029	8.6	29	11.5
1.030	8.4	30	11.4

TABLE 2 Continued

Hydrometer 151H		Hydrometer 152 H	
Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm
1.031	8.1	31	11.2
1.032	7.8	32	11.1
1.033	7.6	33	10.9
1.034	7.3	34	10.7
1.035	7.0	35	10.6
1.036	6.8	36	10.4
1.037	6.5	37	10.2
1.038	6.2	38	10.1
		39	9.9
		40	9.7
		41	9.6
		42	9.4
		43	9.2
		44	9.1
		45	8.9
		46	8.8
		47	8.6
		48	8.4
		49	8.3
		50	8.1
		51	7.9
		52	7.8
		53	7.6
		54	7.4
		55	7.3
		56	7.1
		57	7.0
		58	6.8
		59	6.6
		60	6.5

[A] Values of effective depth are calculated from the equation:

$$L = L_1 + \tfrac{1}{2}[L_2 - (V_B/A)]$$

where:

L = effective depth, cm,
L_1 = distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading, cm,
L_2 = overall length of the hydrometer bulb, cm,
V_B = volume of hydrometer bulb, cm³, and
A = cross-sectional area of sedimentation cylinder, cm²

Values used in calculating the values in Table 2 are as follows:

For both hydrometers, 151H and 152H:
L_2 = 14.0 cm
V_B = 67.0 cm³
A = 27.8 cm²

For hydrometer 151H:
L_1 = 10.5 cm for a reading of 1.000
= 2.3 cm for a reading of 1.031

For hydrometer 152H:
L_1 = 10.5 cm for a reading of 0 g/litre
= 2.3 cm for a reading of 50 g/litre

TABLE 3 Values of K for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis

Temperature, °C	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01510	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.1323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01255	0.01208	0.01191	0.01175
29	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149

3/4"

No. 18 BW Ga = 0.049"

Chrome Plated

1/2"

Punch 0.203" ±0.001"
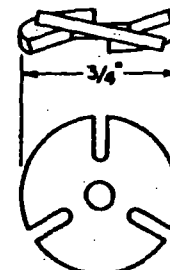
(a)   (b)

Metric Equivalents

in.	0.001	0.049	0.203	½	¾
mm	0.03	1.24	5.16	12.7	19.0

FIG. 1 Detail of Stirring Paddles

Standard Test Method for

AMOUNT OF MATERIAL IN SOILS FINER THAN THE NO. 200 (75-µm) SIEVE[1]

1. Scope

1.1 This method covers determination of the total amount of material in soils finer than the No. 200 (75-µm) sieve.

2. Apparatus

2.1 *Sieves*—A nest of two sieves, the lower being a No. 200 (75-µm) sieve and the upper a No. 40 (425-µm) sieve, both conforming to ASTM Specification E 11, for Wire-Cloth Sieves for Testing Purposes.[2]

2.2 *Containers*—A pan or vessel of sufficient size to contain the test sample covered with water and to permit of vigorous agitation without advertent loss of any part of the sample, and a second pan or container for use in drying the test sample after washing.

3. Test Sample

3.1 The test sample shall be selected from material that has been thoroughly mixed. A representative sample, sufficient to yield not less than the approximate weight of dried material shown in the following table, shall be selected using a sample splitter or by the method of quartering:

Nominal Diameter of Largest Particle, in.	Approximate Minimum Weight of Sample, g
0.0787 (No. 10 sieve) (2.0 mm)	200
0.187 (No. 4 sieve) (4.75 mm)	500
¾ (19.0 mm)	1500
1 (25.0 mm)	2000
1½ or over (37.5 mm)	2500

4. Procedure

4.1 Dry the test sample to a constant weight at a temperature not exceeding 230 ± 9 F (110 ± 5 C) and weigh to the nearest 0.05 percent, or alternatively, weigh the test sample moist and use an auxiliary moisture content sample to determine the moisture content of the sample. The weight of the moisture content sample shall be between 20 and 30 percent of the weight of the test sample. Calculate the oven-dry weight of the test sample from the moist weight and the moisture content.

4.2 Place the test sample in the container, add sufficient clean water to cover it, and allow to soak a minimum of 2 h (preferably overnight).

4.3 Agitate the contents of the container vigorously and pour the wash water immediately over the nested sieves, arranged with the coarser sieve on top. Repeat the process of adding clear water to the container to cover the sample, agitating the contents of the container, and pouring the wash water over the nested sieves until the wash water is clear. When the total sample is small, the entire contents of the soaking container may be transferred to the nested sieves after the first washing and the washing operation completed in accordance with 4.4. The wash water need not be saved.

NOTE 1—The percentage value secured at the end of the test may not be correct (being too low) for soils containing relatively high percentages of the minus 200 fraction. This appears to be due chiefly to inadequate agitation. When it is desired to secure the exact per-

centage for the minus 200 fraction for such a soil, the portion of the sample passing the No. 40 sieve and retained on the No. 200 sieve secured in the washing operation, shall be transferred to the dispersion cup of the stirring apparatus used in Method D 422, Particle-Size Analysis of Soils,[3] the cup filled half full with water and the contents agitated for 1 min. After this agitation the contents of the cup shall be transferred to the nested sieves and washing continued.

If the stirring apparatus has not been used prior to the drying of the portion of the sample larger than the No. 200 (75-μm) sieve, and it is desired to do so after drying, the dried material shall be separated on the No. 40 (425-μm) sieve; the portion retained shall be saved; and the portion passing shall be placed in the dispersion cup with water and agitated for 1 min with the stirring apparatus as previously described. The contents of the cup shall be transferred to the No. 200 sieve, washed, and dried. The revised total weight retained on the No. 200 sieve shall be secured by combining and weighing the two fractions.

4.4 Transfer the sample to the nested sieves and wash with running water (Note 2). When the sample is larger than can be handled at one time on the nested sieves, wash a portion of the sample and transfer to the container in which it is to be dried.

NOTE 2—Tapping of sieves has been found to expedite the washing operations.

4.5 Dry the washed material retained on the nested sieves in a container to a constant weight at a temperature not exceeding 230 ± 9 F (110 ± 5 C) and dry-sieve it on the nested sieves (Note 3). Weigh the dry material retained on the nested sieves to the nearest 0.05 percent.

NOTE 3—Some material passes the No. 200 (75-μm) sieve on dry sieving that did not pass during the washing operation. When desired, a sieve analysis may be made on the portion of the sample retained on the No. 200 sieve, in accordance with Method D 422.

5. Calculation

5.1 Calculate the results as follows:

$$P = [(W_o - W_1)/W_o] \times 100$$

P = percentage of material finer than No. 200 (75-μm) sieve,

W_o = weight of original sample on an oven-dry basis, g and

W_1 = oven-dry weight of sample after washing and dry-sieving, g

[3] Annual Book of ASTM Standards, Vol 04.08.

Designation: D 698 – 78

An American National Standard

Standard Test Methods for
MOISTURE-DENSITY RELATIONS OF SOILS AND SOIL-AGGREGATE MIXTURES USING 5.5-lb (2.49-kg) RAMMER AND 12-in. (305-mm) DROP[1]

This standard is issued under the fixed designation D 698; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

These methods have been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 These laboratory compaction methods cover the determination of the relationship between the moisture content and density of soils and soil-aggregate mixtures (Note 1) when compacted in a mold of a given size with a 5.5-lb (2.49-kg) rammer dropped from a height of 12 in. (305 mm) (Note 2). Four alternative procedures are provided as follows:

1.1.1 *Method A*—A 4-in. (101.6-mm) mold; material passing a No. 4 (4.75-mm) sieve;

1.1.2 *Method B*—A 6-in. (152.4-mm) mold; material passing a No. 4 (4.75-mm) sieve;

1.1.3 *Method C*—A 6-in. (152.4-mm) mold; material passing a ¾-in. (19.0-mm) sieve; and

1.1.4 *Method D*—A 6-in. (152.4-mm) mold; material passing a ¾-in. (19.0-mm) sieve, corrected by replacement for material retained on a ¾-in. sieve.

NOTE 1—Soils and soil-aggregate mixtures should be regarded as natural occurring fine- or coarse-grained soils or composites or mixtures of natural soils, or mixtures of natural and processed soils or aggregates such as silt, gravel, or crushed rock.

NOTE 2—These laboratory compaction test methods when used on soils and soil-aggregates which are not free-draining will, in most cases, establish a well-defined optimum moisture content and maximum density (see Section 7). However, for free-draining soils and soil-aggregate mixtures, these methods will not, in many cases, produce a well-defined moisture-density relationship and the maximum density obtained will generally be less than that obtained by vibratory methods.

1.2 The method to be used should be indicated in the specifications for the material being tested. If no method is specified, the provisions of Section 5 shall govern.

2. Applicable Documents

2.1 *ASTM Standards:*

C 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate[2]

D 854 Test Method for Specific Gravity of Soils[3]

D 2168 Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors[3]

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[3]

D 2487 Test Method for Classification of Soils for Engineering Purposes[3]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[3]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[4]

3. Apparatus

3.1 *Molds*—The molds shall be cylindrical in shape, made of rigid metal and be within the capacity and dimensions indicated in 3.1.1 or 3.1.2. The molds may be the "split" type, consisting either of two half-round sections, or a

[1] These methods are under the jurisdiction of ASTM Committee D-18 on Soil and Rock.
Current edition approved April 27, 1978. Published July 1978. Originally published as D 698 – 42 T. Last previous edition D 698 – 70.
[2] Annual Book of ASTM Standards, Vols 04.02 and 04.03.
[3] Annual Book of ASTM Standards, Vol 04.08.
[4] Annual Book of ASTM Standards, Vols 04.01, 04.02, 04.06, 05.05, and 14.02.

section of pipe split along one element, which can be securely locked together to form a cylinder meeting the requirements of this section. The molds may also be the "taper" type, providing the internal diameter taper is uniform and is not more than 0.200 in./linear ft (16.7 mm/linear m) of mold height. Each mold shall have a base plate assembly and an extension collar assembly, both made of rigid metal and constructed so they can be securely attached to or detached from the mold. The extension collar assembly shall have a height extending above the top of the mold of at least 2 in. (50.8 mm), which may include an upper section that flares out to form a funnel provided there is at least a ¼-in. (19-mm) straight cylindrical section beneath it.

3.1.1 *Mold*, 4.0 in. (101.6 mm) in diameter, having a capacity of ¹⁄₃₀ ± 0.0004 ft³ (944 ± 11 cm³) and conforming to Fig. 1.

3.1.2 *Mold*, 6.0 in. (152.4 mm) in diameter, having a capacity of ¹⁄₁₃.₃₃₃ ± 0.0009 ft³ (2124 ± 25 cm³) and conforming to Fig. 2.

3.1.3 The average internal diameter, height, and volume of each mold shall be determined before initial use and at intervals not exceeding 1000 times the mold is filled. The mold volume shall be calculated from the average of at least six internal diameter and three height measurements made to the nearest 0.001 in. (0.02 mm), or from the amount of water required to completely fill the mold, corrected for temperature variance in accordance with Table 1. If the average internal diameter and volume are not within the tolerances shown in Figs. 1 or 2, the mold shall not be used. The determined volume shall be used in computing the required densities.

3.2 *Rammer*—The rammer may be either manually operated (see 3.2.1) or mechanically operated (see 3.2.2). The rammer shall fall freely through a distance of 12.0 ± ¹⁄₁₆ in. (304.8 ± 1.6 mm) from the surface of the specimen. The manufactured weight of the rammer shall be 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The specimen contact face shall be flat.

3.2.1 *Manual Rammer*—The specimen contact face shall be circular with a diameter of 2.000 ± 0.005 in. (50.80 ± 0.13 mm). The rammer shall be equipped with a guidesleeve which shall provide sufficient clearance so that the free fall of the rammer shaft and

head will not be restricted. The guidesleeve shall have four vent holes at each end (eight holes total) located with centers ¾ ± ¹⁄₁₆ in. (19.0 ± 1.6 mm) from each end and spaced 90 deg apart. The minimum diameter of the vent holes shall be ⅜ in. (9.5 mm).

3.2.2 *Mechanical Rammer*—The rammer shall operate mechanically in such a manner as to provide uniform and complete coverage of the specimen surface. There shall be 0.10 ± 0.03 in. (2.5 ± 0.8 mm) clearance between the rammer and the inside surface of the mold at its smallest diameter. When used with the 4.0-in. (101.6-mm) mold, the specimen contact face shall be circular with a diameter of 2.000 ± 0.005 in. (50.80 ± 0.13 mm). When used with the 6.0-in. (152.4-mm) mold, the specimen contact face shall have the shape of a section of a circle of a radius equal to 2.90 ± 0.02 in. (73.7 ± 0.5 mm). The sector face rammer shall operate in such a manner that the vertex of the sector is positioned at the center of the specimen. The mechanical rammer shall be calibrated and adjusted, as necessary, in accordance with 3.2.3.

3.2.3 *Calibration and Adjustment*—The mechanical rammer shall be calibrated, and adjusted as necessary, before initial use; near the end of each period during which the mold was filled 1000 times; before reuse after anything, including repairs, which may affect the test results significantly; and whenever the test results are questionable. Each calibration and adjustment shall be in accordance with Methods D 2168.

3.3 *Sample Extruder* (optional)—A jack, frame or other device adapted for the purpose of extruding compacted specimens from the mold.

3.4 *Balances*—A balance or scale of at least 20-kg capacity sensitive to ± 1 g and a balance of at least 1000-g capacity sensitive to ±0.01 g.

3.5 *Drying Oven*, thermostatically controlled, preferably of the forced-draft type, capable of maintaining a temperature of 230 ± 9°F (110 ± 5°C) for determining the moisture content of the compacted specimen.

3.6 *Straightedge*—A stiff metal straightedge of any convenient length but not less than 10 in. (254 mm). The scraping edge shall have a straightness tolerance of ±0.005 in. (±0.13 mm) and shall be beveled if it is thicker than ⅛ in.

(3 mm).

3.7 *Sieves*. 3-in. (75-mm), ¼-in. (19.0-mm) and No. 4 (4.75-mm), conforming to the requirements of Specification E 11.

3.8 *Mixing Tools* — Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

4. Procedure

4.1 *Specimen Preparation* — Select a representative portion of quantity adequate to provide, after sieving, an amount of material weighing as follows: Method A — 25 lb (11 kg); Methods B, C, and D — 50 lb (23 kg). Prepare specimens in accordance with either 4.1.1 through 4.1.3 or 4.1.4.

4.1.1 *Dry Preparation Procedure* — If the sample is too damp to be friable, reduce the moisture content by drying until the material is friable; see 4.1.2. Drying may be in air or by the use of a drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). After drying (if required), thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of the particles. Pass the material through the specified sieve as follows: Methods A and B — No. 4 (4.75-mm); Methods C and D — ¼-in. (19.0-mm). Correct for oversize material in accordance with Section 5, if Method D is specified.

4.1.2 Whenever practicable, soils classified as ML, CL, OL, GC, SC, MH, CH, OH and PT by Test Method D 2487 shall be prepared in accordance with 4.1.4.

4.1.3 Prepare a series of at least four specimens by adding increasing amounts of water to each sample so that the moisture contents vary by approximately 1½ %. The moisture contents selected shall bracket the optimum moisture content, thus providing specimens which, when compacted, will increase in mass to the maximum density and then decrease in density (see 7.2 and 7.3). Thoroughly mix each specimen to ensure even distribution of moisture throughout and then place in a separate covered container and allow to stand prior to compaction in accordance with Table 2. For the purpose of selecting a standing time, it is not required to perform the

actual classification procedures described in Test Method D 2487 (except in the case of referee testing), if previous data exist which provide a basis for classifying the sample.

4.1.4 *Moist Preparation Method* — The following alternate procedure is recommended for soils classified as ML, CL, OL, GC, SC, MH, CH, OH, and PT by Test Method D 2487. Without previously drying the sample, pass it through the ¼-in. (19.0-mm) and No. 4 (4.75-mm) sieves. Correct for oversize material in accordance with Section 5, if Method D is specified. Prepare a series of at least four specimens having moisture contents that vary by approximately 1½ %. The moisture contents selected shall bracket the optimum moisture content, thus providing specimens which, when compacted, will increase in mass to the maximum density and then decrease in density (see 7.2 and 7.3). To obtain the appropriate moisture content of each specimen, the addition of a predetermined amount of water (see 4.1.3) or the removal of a predetermined amount of moisture by drying may be necessary. Drying may be in air or by the use of a drying apparatus such that the temperature of the specimen does not exceed 140°F (60°C). The prepared specimens shall then be thoroughly mixed and stand, as specified in 4.1.3 and Table 2, prior to compaction.

NOTE 3 — With practice, it is usually possible to visually judge the point of optimum moisture closely enough so that the prepared specimens will bracket the point of optimum moisture content.

4.2 *Specimen Compaction* — Select the proper compaction mold, in accordance with the method being used, and attach the mold extension collar. Compact each specimen in three layers of approximately equal height. Each layer shall receive 25 blows in the case of the 4-in. (101.6-mm) mold; each layer shall receive 56 blows in the case of the 6-in. (152.4-mm) mold. The total amount of material used shall be such that the third compacted layer is slightly above the top of the mold, but not exceeding ¼ in. (6 mm). During compaction the mold shall rest on a uniform rigid foundation, such as provided by a cylinder or cube of concrete weighing not less than 200 lb (91 kg).

4.2.1 In operating the manual rammer, care shall be taken to avoid rebound of the rammer from the top end of the guidesleeve.

The guidesleeve shall be held steady and within 5 deg of the vertical. Apply the blows at a uniform rate not exceeding approximately 1.4 s per blow and in such a manner as to provide complete coverage of the specimen surface.

4.2.2 Following compaction, remove the extension collar; carefully trim the compacted specimen even with the top of the mold by means of the straightedge and determine the mass of the specimen. Divide the mass of the compacted specimen and mold, minus the mass of the mold, by the volume of the mold (see 3.1.3). Record the result as the wet density, γ_m, in pounds per cubic foot (or kilograms per cubic metre) of the compacted specimen.

4.2.3 Remove the material from the mold. Determine moisture content in accordance with Method D 2216, using either the whole specimen or alternatively a representative specimen of the whole specimen. The whole specimen must be used when the permeability of the compacted specimen is high enough so that the moisture content is not distributed uniformly throughout. If the whole specimen is used, break it up to facilitate drying. Obtain the representative specimen by slicing the compacted specimen axially through the center and removing 100 to 500 g of material from one of the cut faces.

4.2.4 Repeat 4.2 through 4.2.3 for each specimen prepared.

5. Oversize Corrections

5.1 If 30 % or more of the sample is retained on a ¼-in. (19.0-mm) sieve, then none of the methods described under these methods shall be used for the determination of either maximum density or optimum moisture content.

5.2 *Methods A and B* — The material retained on the No. 4 (4.75-mm) sieve is discarded and no oversize correction is made. However, it is recommended that if the amount of material retained is 7 % or greater, Method C be used instead.

5.3 *Method C* — The material retained on the ¼-in. (19.0-mm) sieve is discarded and no oversize correction is made. However, if the amount of material retained is 10 % or greater, it is recommended that Method D be used instead.

5.4 *Method D*:

5.4.1 This method shall not be used unless the amount of material retained on the ¼-in. (19.0-mm) sieve is 10 % or greater. When the amount of material retained on the ¼-in. sieve is less than 10 %, use Method C.

5.4.2 Pass the material retained on the ¼-in. (19.0-mm) sieve through a 3-in. or 75-mm sieve. Discard the material retained on the 3-in. sieve. The material passing the 3-in. sieve and retained on the ¼-in. sieve shall be replaced with an equal amount of material passing a ¼-in. sieve and retained on a No. 4 (4.75-mm) sieve. The material for replacement shall be taken from an unused portion of the sample.

6. Calculations

6.1 Calculate the moisture content and the dry density of each compacted specimen as follows:

$$w = [(A - B)/(B - C)] \times 100$$

and

$$\gamma_d = [\gamma_m/(w + 100)] \times 100$$

where:

- w = moisture content in percent of the compacted specimens,
- A = mass of container and moist specimen,
- B = mass of container and oven-dried specimen,
- C = mass of container,
- γ_d = dry density, in pounds per cubic foot (or kilograms per cubic metre) of the compacted specimen, and
- γ_m = wet density, in pounds per cubic foot (or kilograms per cubic metre) of the compacted specimen.

7. Moisture-Density Relationship

7.1 From the data obtained in 6.1, plot the dry density values as ordinates with corresponding moisture contents as abscissas. Draw a smooth curve connecting the plotted points. Also draw a curve termed the "curve of complete saturation" or "zero air voids curve" on this plot. This curve represents the relationship between dry density and corresponding moisture contents when the voids are completely filled with water. Values of dry density and corresponding moisture contents for plotting the curve of complete saturation can be com-

puted using the following equation:

$$w_{sat} = [(62.4/\gamma_d) - (1/G_s)] \times 100$$

where:

w_{sat} = moisture content in percent for complete saturation,

γ_d = dry density in pounds per cubic foot (or kilograms per cubic metre),

G_s = specific gravity of the material being tested (see Note 4), and

62.4 = density of water in pounds per cubic foot (or kilograms per cubic metre).

NOTE 4—The specific gravity of the material can either be assumed or based on the weighted average values of: (a) the specific gravity of the material passing the No. 4 (4.75-mm) sieve in accordance with Test Method D854; and (b) the apparent specific gravity of the material retained on the No. 4 sieve in accordance with Test Method C127.

7.2 *Optimum Moisture Content, w_o*—The moisture content corresponding to the peak of the curve drawn as directed in 7.1 shall be termed the "optimum moisture content."

7.3 *Maximum Density, γ_{max}*—The dry density in pounds per cubic foot (or kilograms per cubic metre) of the sample at "optimum moisture content" shall be termed "maximum density."

8. Report

8.1 The report shall include the following.

8.1.1 Method used (Method A, B, C, or D).

8.1.2 Optimum moisture content.

8.1.3 Maximum density.

8.1.4 Description of rammer (whether manual or mechanical).

8.1.5 Description of appearance of material used in test, based on Practice D2488 (Test Method D2487 may be used as an alternative).

8.1.6 Origin of material used in test.

8.1.7 Preparation procedure used (moist or dry).

9. Precision

9.1 Criteria for judging the acceptability of the maximum density and optimum moisture content test results are given in Table 3. The standard deviation, s, is calculated from the equation:

$$s^2 = \frac{1}{n-1}\sum_1^k (x - \bar{x})^2$$

where:

n = number of determinations,

x = individual value of each determination, and

$\bar{x}$ = numerical average of the determinations.

9.2 Criteria for assigning standard deviation values for single-operator precision are not available at the present time.

**TABLE 1 Volume of Water per Gram based on Temperature**

Temperature, °C (°F)	Volume of Water, ml/g
12 (53.6)	1.00048
14 (57.2)	1.00073
16 (60.8)	1.00103
18 (64.4)	1.00138
20 (68.0)	1.00177
22 (71.6)	1.00221
24 (75.2)	1.00268
26 (78.8)	1.00320
28 (82.4)	1.00375
30 (86.0)	1.00435
32 (89.6)	1.00497

*Values other than shown may be obtained by referring to the Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., Cleveland, Ohio.

TABLE 2 Dry Preparation Method—Standing Times

Classification D 2487	Minimum Standing Time, h
GW, GP, SW, SP	no requirement
GM, SM	3
ML, CL, OL, GC, SC	18
MH, CH, OH, PT	36

TABLE 3 Precision

	Standard Deviation, s	Acceptable Range of Two Results, Expressed as Percent of Mean Value*
Single-operator precision:		
Maximum density	...	1.9
Optimum moisture content	...	9.5
Multilaboratory precision:		
Maximum density	±1.66	4.0
Optimum moisture content	±0.86	15.0

* This column indicates a limiting range of values which should not be exceeded by the difference between any two results, expressed as a percentage of the average value. In cooperative test programs it has been determined that 95 % of the tests do not exceed the limiting acceptable ranges shown below. All values shown in this table are based on average test results from a variety of different soils and are subject to future revision.

TABLE 4 Metric Equivalents for Figs. 1 and 2

in.	mm
0.016	0.41
0.026	0.66
1/32	0.80
1/16	1.6
1/8	3.2
1/4	6.4
11/32	8.7
3/8	9.5
1/2	12.7
5/8	15.9
2	50.8
2 1/2	63.5
4	101.6
4 1/4	108.0
4 1/2	114.3
4.584	116.43
6	152.4
6 1/2	165.1
8	203.2

ft³	cm³
1/30	944
0.004	11
1/13.333	2124
0.0009	25
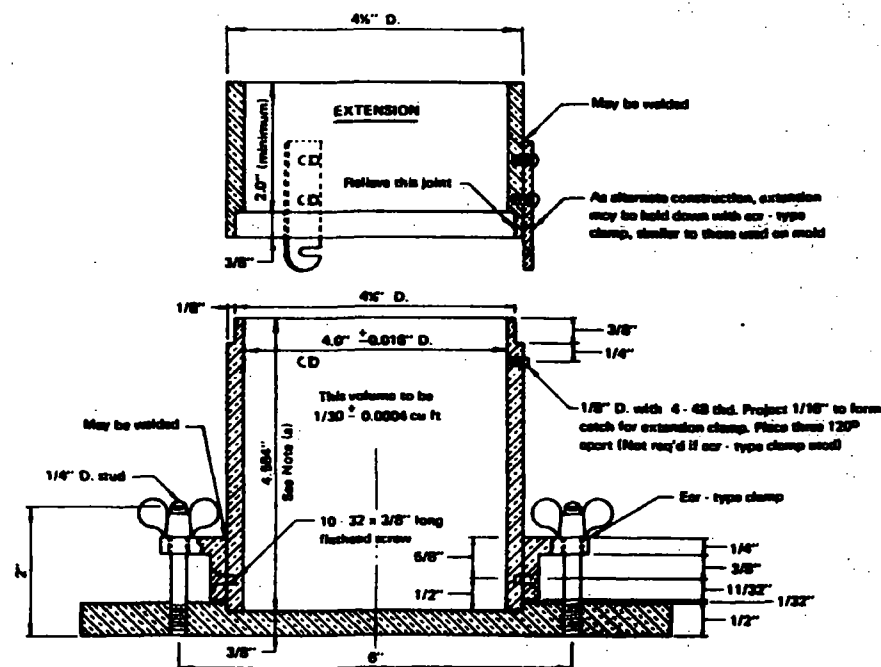
NOTE 1—The tolerance on the height is governed by the allowable volume and diameter tolerances.
NOTE 2—The methods shown for attaching the extension collar to the mold and the mold to the base plate are recommended. However, other methods are acceptable, providing the attachments are equally as rigid as those shown.

FIG. 1 Cylindrical Mold, 4.0-in. for Soil Tests (see Table 4 for metric equivalents).
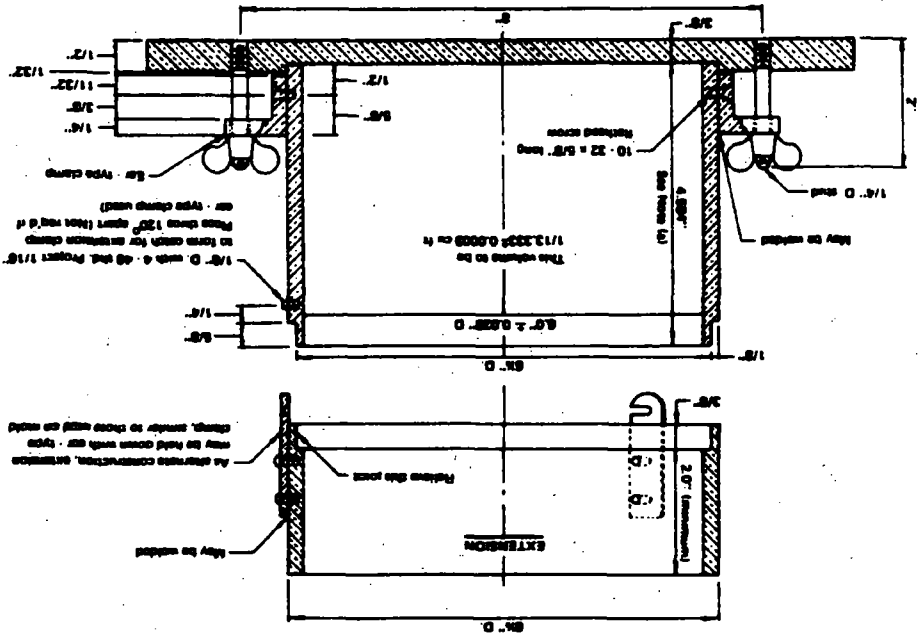
Designation: D 2435 – 80

An American National Standard

Standard Test Method for
ONE-DIMENSIONAL CONSOLIDATION PROPERTIES OF SOILS[1]

This standard is issued under the fixed designation D 2435; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This method covers a procedure for determining the rate and magnitude of consolidation of soil when it is restrained laterally and loaded and drained axially.

1.2 The values stated in SI units are to be regarded as the standard. The values stated in inch-pound units are approximate.

2. Applicable Documents

2.1 ASTM Standards:
D 422 Method for Particle-Size Analysis of Soils[2]
D 423 Test Method for Liquid Limit of Soils[3]
D 424 Test Method for Plastic Limit and Plasticity Index of Soils[3]
D 854 Test Method for Specific Gravity of Soils[2]
D 1587 Method for Thin-Walled Tube Sampling of Soils[2]
D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[3]
D 3550 Practice for Ring-Lined Barrel Sampling of Soils[3]

3. Summary of Method

3.1 The method requires that an element of soil be restrained laterally and axially loaded in increments with a constant stress being applied until all of the excess pore water pressures have dissipated for each increment. During the compression process measurements of decrease in the sample height are made and these data are used to compute the parameters that describe the relationship between the effective stress and void ratio or strain and describe the rate at which compression can occur.

4. Significance and Use

4.1 The compressibility of soils as determined from this test is one of the most useful properties that can be obtained from laboratory testing. The data from the consolidation test can be used to develop an estimate of both the rate and the amount of both differential and total settlement of a structure or a landfill. Estimates of this type are often of key importance in first selecting a foundation type and secondly in evaluating its adequacy.

5. Apparatus

5.1 Load Device—A suitable device for applying vertical loads to the specimen. The device should be capable of maintaining specified loads for long periods of time with an accuracy of ± 0.5 % of the applied load and should permit application of a given load increment within a period of 2 s. without significant impact.

5.2 Consolidometer—A device to hold the specimen in a ring which is either fixed to the base or floating (supported by friction on periphery of specimen) with porous stones on each face of the specimen. The consolidometer shall also provide means for submerging the specimen, for applying a vertical load, and for measuring the change in height of specimen. The consolidometer ring shall conform to the following requirements:

5.2.1 Minimum Specimen (Ring) Diameter—The minimum specimen diameter shall be 50 mm (2.00 in.), and shall be at least 5 mm (¼ in.) less than the inside diameter of the sample tube if samples are extruded and trimmed.

5.2.2 Minimum Specimen Height—The minimum specimen height shall be 13 mm (0.5 in.) but shall be not less than 10 times the maximum particle diameter.

5.2.3 Minimum Specimen Diameter-to-Height Ratio—The minimum specimen diameter-to-height ratio shall be 2.5.

5.2.4 Rigidity—The rigidity of the ring shall be such that, under hydrostatic stress conditions in the specimen, the change in diameter of the ring will not exceed 0.03 % of the diameter under the greatest load applied.

5.2.5 The ring shall be made of a material that is noncorrosive in relation to the soil tested. The inner surface shall be highly polished or shall be coated with a low-friction material. Silicon grease is recommended or polytetrafluoroethylene for nonsandy soils.

5.3 Porous Stones—The porous stones shall be of silicon carbide, aluminum oxide, or metal that is not attacked by the soil or soil moisture. The grade of the stones shall be fine enough to prevent intrusion of soil into the pores of the stone. If necessary, a filter paper[2] may be used to prevent intrusion of the soil into the stones. However, the permeability of the stones, and filter paper, if used, must be sufficiently high to prevent retardation of the drainage of the specimen. The stones shall be clean and free of cracks, chips, and nonuniformities.

5.3.1 The diameter of the top stone shall be 0.2 to 0.5 mm (0.01 to 0.02 in.) less than that of the inside diameter of the ring. If a floating ring is used, the bottom stone shall have the same diameter as the top stone. The use of tapered stones is recommended, with the larger diameter in contact with the soil.

5.3.2 The stone thickness shall be sufficient to prevent breaking. The top stone shall be loaded through a corrosion-resistant plate of sufficient rigidity to prevent breakage of the stone.

5.4. Storage—Storage of sealed samples should be such that no moisture is lost during storage, that is, no evidence of partial drying of the ends of the samples or shrinkage. Time of storage should be minimized, particularly when the soil or soil moisture is expected to react with the sample tubes.

5.4.1 Sample Preparation Environment—

Test specimens shall be prepared in an environment where soil moisture change during preparation does not exceed 0.2 %. (A high humidity moisture room is usually used for this purpose.)

5.5 Temperature—Tests should be performed in an environment where temperature fluctuations are less than ± 4°C (7.2°F) and there is not any direct contact with sunlight.

5.6 Trimmer, or cylindrical cutter, for trimming the sample down to the inside diameter of the consolidometer ring with a minimum of disturbance. The cutter shall have a highly polished surface and be coated with a low-friction material.

5.7 Balance, sensitive to 0.1 g or to 0.1 % of the total mass of the test specimen.

5.8 Drying Oven, that can be maintained uniformly at 110 ± 5°C (230 ± 9°F). A forced-draft oven is recommended.

5.9 Extensometer, to measure change in height of the specimen with a sensitivity of 0.0025 mm (0.0001 in.).

5.10 Miscellaneous Equipment, including spatulas, knives, wire saws, used in preparing the specimen.

5.11 Moisture Content Containers, shall be in accordance with Method D 2216.

6. Sampling

6.1 Relatively undisturbed samples should be obtained and used for consolidation testing because the meaningfulness of the results diminishes greatly with sample disturbance. Method D 1587 and Practice D 3550 cover procedures and apparatus that may be used to obtain satisfactory samples for testing.

7. Specimen Preparation (Note 2)

7.1 Prepare the sample in an environment in accordance with 5.4.1. Trim the specimen to the inside diameter of the consolidometer, forcing it directly into the ring during trimming. Trim it flush with the plane surface of the ring. For soft to medium soils, a wire saw should be used for trimming the top and bottom of the specimen to minimize smearing. A straightedge with a sharp cutting edge may be used for the final trim after the excess soil has first been removed with a wire saw. For stiff soils, a sharpened straightedge alone may be used for

[2] Use a hardened, fast filter paper.

trimming the top and bottom. If desired, the specimen height may be made less than the ring height by partial extrusion and trimming, provided the minimum specimen thickness requirements in 5.2.2 and 5.2.3 are met. A specimen ring with the cutting edge attached provides the most accurate fit in moist soils.

NOTE—Precautions should be taken to minimize disturbance of the soil or changes in moisture and density during sample transportation and preparation. Vibration, distortion, and compression must be avoided.

7.2 Fibrous soils, such as peat, and those soils that are easily damaged by trimming, may be transferred directly from the sampling tube to the ring provided that the ring has the same diameter as the sample tube.

7.3 Specimens obtained using a ring-lined sampler may be used without prior trimming, provided they comply with the requirements of Practice D 3550 and this method.

7.4 Determine the mass of the specimen in the consolidation ring.

8. Calibration

8.1 Assemble the consolidometer with a copper or hard steel disk of approximately the same height as the test specimen and 1 mm (0.04 in.) smaller diameter than the ring in place of the sample. Moisten the porous stones. If filter papers are to be used (see 5.3), they should be moistened and sufficient time for the moisture to be squeezed from them should be allowed during the calibration process.

8.2 Load and unload the consolidometer as in the test and measure the deformation for each load applied.

8.3 Plot or tabulate the corrections to be applied to the deformation of the test specimen at each load applied. Note that the metal disk will deform also. However, the correction due to this deformation will be negligible for all but extremely stiff soils. If necessary, the compression of the metal disk can be computed and applied to the corrections.

9. Natural Moisture Content, Weight, Volume, Specific Gravity, Liquid and Plastic Limits, and Particle Size Distribution Determinations

9.1 Use the material trimmed adjacent to the specimen (see Section 7) to determine the natural moisture content in accordance with

Method D 2216 and the specific gravity with Test Method D 854. Determine the initial wet mass of the specimen by subtracting the mass of the specimen ring from the combined mass of the specimen ring and the specimen. Determine the initial volume of the specimen from the diameter and height of the specimen. The value of moisture content determined from the trimmings is approximate but permits determination of the void ratio before the test is complete. The most accurate determination of the specimen dry mass and moisture content is found by drying the entire specimen at the end of the test. This procedure should be used unless a portion of the specimen is needed for index tests (see 10.9). The specific gravity can be estimated where an accurate void ratio is not needed.

9.2 The liquid limit, as determined in accordance with Test Method D 423, the plastic limit, as determined in accordance with Test Method D 424, and the particle size distribution, for soils with substantial granular material, as determined in accordance with Method D 422, are useful in identifying the soil and in correlating the results of tests on different soils. It is recommended that liquid and plastic limits be determined on the trimmings or on representative portions of the test specimen if the soil exhibits significant heterogeneity.

10. Procedure

10.1 The objective of the preparation of the stones and other apparatus prior to their contact with the specimen is to prevent change in moisture content of the specimen. Thus, very dry, highly expansive soils should be placed on dry stones but most partially saturated soils may be placed on stones that have simply been dampened. If the specimen is saturated and is believed not to exhibit a high affinity for water, the porous stones should be boiled after cleaning with a nonabrasive brush and kept saturated until the time of their contact with the specimen. Assemble the ring, specimen and porous stones. With the consolidometer assembled, enclose the specimen, ring, filter paper (when used), and porous stones with a loose-fitting plastic or rubber membrane to prevent change in specimen volume due to evaporation. This step may be omitted if the specimen is to be inundated after the first load increment is applied as provided in 10.8.

10.2 Place the consolidometer in the loading device and apply a seating pressure of 5 kPa (100 lbf/ft²). Within 5 min after application of the seating load, adjust the extensometer dial gage for the initial or zero reading. (For very soft soils a seating pressure of 2 or 3 kPa (about 50 lb/ft²) or less is desirable.)

10.3 Place loads on the consolidometer to obtain pressures on the soil of approximately 5, 10, 20, 40, 80, etc., kPa (100, 200, 400, 800, 1600, etc., lbf/ft²), with each pressure maintained constant as required in 10.4. (Smaller increments may be desirable on very soft specimens or when it is desirable to determine the preconsolidation pressure with more precision.) Loading of the specimen should continue into the virgin compression region so that the slope and shape of the virgin compression curve may be assessed. Typically, a final pressure that is equal to or greater than four times the preconsolidation pressure of the sample is required for this assessment. In the case of overconsolidated clays in particular, it may be desirable to use an unloading-reloading cycle to better evaluate recompression parameters, but such a procedure is optional.

10.4 For at least two load increments (including at least one load increment after the preconsolidation pressure has been exceeded), record the height or change in height of the specimen before each pressure increment is applied and at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, and 30 min, 1, 2, 4, 8, etc., h, measured from the time of each incremental pressure application. These time-rate readings need be obtained only for saturated specimens. Readings should continue at least until the slope of the characteristic linear secondary compression portion of the thickness versus log of time plot is apparent (see 11.1), unless the method 11.6 is used, in which case the next loading may proceed as soon as 100 % consolidation is completed. (For soils that have slow primary consolidation, pressures should be applied for at least 24 h. In extreme cases, or where secondary compression must be evaluated, they should be applied much longer.) Then apply the next pressure increment. For pressure increments where time versus deformation data are not required, the load should be left on the sample for essentially the same length of time as when time versus defor-

mation readings are taken. Sufficient readings should be taken near the end of the pressure increment period to allow for any needed extrapolation of the time-deformation curve.

10.5 If thickness versus square root of time plots are to be made, the time intervals may be adjusted to those that have easily obtained square roots, for example, 0.09, 0.25, 0.49, 1 min, 4 min, 9 min, etc.

10.6 Rebound—Where rebound or unloading characteristics are desired, unload soil by pressure decrements in reverse order. However, if desired, each successive load can be only one fourth as large as the preceding load. Record at time intervals as suggested in 10.4. Note, however, that for most soils the rebound will be complete in less time than would be required for an increment of load during primary consolidation, but sufficient readings should be taken to verify that rebound is essentially complete.

10.7 An alternative loading, unloading, or reloading schedule may be employed that reproduces the construction stress changes, or obtains better definition of some part of the stress-deformation curve, or aids in interpreting the field behavior of the soil. This should be clearly indicated on the test results.

10.8 If the test is performed on an undisturbed sample that was either saturated under field conditions or obtained from below the water table, it should be inundated after the first load increment is applied. As inundation and specimen wetting occur, the load should be increased if required, to prevent the specimen from swelling, unless it tends to swell under the estimated in situ vertical stress. If the specimen compresses after inundation, simply record the amount of compression. Specimens also may be inundated at pressures that simulate future inundation under field conditions. In such cases, the pressure at inundation and any resulting effects, such as expansion or increased compression, should be noted in the test results.

10.9 To minimize swell during disassembly, the specimen should be rebounded back to a very small stress and dismantled quickly after releasing the final load on the specimen. Remove the specimen and the ring from the consolidometer and wipe the free water from the ring and specimen. Remove the specimen from the ring and determine its mass, oven dry it,

and reweigh it to obtain the dry mass of solids and the final water content. If the original soil sample is very heterogeneous, any index tests should be performed on a portion of the test specimen and the remainder can be used for a final water content measurement. Porous stones should be boiled clean after the test to prevent clay from drying on them and reducing their permeability.

11. Calculation

11.1 From those increments of load where time-rate readings are obtained, plot the deformation readings versus the log of time (in minutes) for each increment of load or pressure as the test progresses, and for any increments of rebound where time versus deformation data have been obtained.

11.2 Find the deformation representing 100 % primary consolidation for each load increment. First draw a straight line through the points representing the final readings and that exhibit a straight line trend and a flat slope. Draw a second straight line tangent to the steepest part of the deformation-log time curve. The intersection represents the deformation corresponding to 100 % primary consolidation. Correct the deformation at 100 % consolidation in accordance with the results of the calibration (see Section 8). Compression that occurs subsequent to 100 % primary consolidation is defined as secondary compression.

11.3 Find the deformation representing 0 % primary consolidation by selecting the deformations at any 2 times that have a ratio of 1 to 4. The deformation corresponding to the larger of the two times should be greater than ¼ but less than ½ of the total change in deformation for the load increment. The deformation corresponding to 0 % primary consolidation is equal to the deformation corresponding to the smaller time interval less the difference in deformations for the two selected times.

11.4 The deformation corresponding to 50 % primary consolidation for each load increment is equal to the average of the uncorrected deformations corresponding to the 0 and 100 % deformations. The time required for 50 % consolidation under any load increment may be found graphically from the deformation-log time curve for that load increment by observing the time that corresponds to 50 % of the primary consolidation of the curve.

11.5 For each load increment for which time-rate readings were obtained, compute the coefficient of consolidation, c_v, as follows:

$$c_v = \frac{0.05 H^2}{t_{50}}$$

where:

H = sample height in metres (feet) for a doubly drained sample at 50 % consolidation,

t_{50} = time for 50 % consolidation in years, and

c_v = coefficient of consolidation in m²/year (ft²/year).

If H is in millimetres and t in seconds or minutes, c_v will be expressed in mm²/s or mm²/min, respectively, and conversion to more convenient units is desirable.

11.6 An alternative procedure requiring a plot of deformation versus the square root of time in minutes may be used to determine the points of 0 and 100 % consolidation as well as the coefficient of consolidation for each load increment. The initial part of the curve is approximated by a straight line. The line is extrapolated back to $t = 0$. The corresponding deformation ordinate represents 0 % primary consolidation. A second straight line is drawn through this point so that the abscissa of this line is 1.15 times the abscissa of the straight line approximation of the initial part of the curve. The intersection of the new line with the deformation-square root of time curve corresponds to 90 % primary consolidation. The deformation at 100 % primary consolidation is ⅑ more than the difference in deformations between 0 and 90 % consolidation. Similarly, the deformation at 50 % consolidation is ⅚ of the difference between that at 0 and 90 %. The coefficient of consolidation can be found from the time of 90 % consolidation by the formula:

$$c_v = \frac{0.21 H^2}{t_{90}}$$

where:

H = sample height for a doubly drained sample at 90 % consolidation, m (or ft),

t_{90} = time for 90 % consolidation, years, and

c_v = coefficient of consolidation, m²/year (ft²/year).

If H is in millimetres and t in seconds or minutes, the units of c_v will be mm²/s or mm²/min, respectively, and conversion to more convenient units is desirable. The square root

of time method may also be used to obtain a value of t_{50}, if desired.

11.7 Compute initial void ratio, water content, unit weight, and degree of saturation, based on the dry weight of the total specimen. Specimen volume is computed from measurements of the container ring height and diameter. Volume of solids is computed by dividing the dry weight of specimen by the specific gravity of the solids times the unit weight of water. Volume of voids is assumed to be the difference between the specimen volume and the volume of the solids.

11.8 Compute void ratio corresponding to 100 % primary consolidation (using corrected deformation readings) for each load. As an alternative, compute percent compression at 100 % primary consolidation for each load from the initial sample height. As a second alternative, compute void ratios (or values of percent compression) using the deformation values obtained after a selected time interval that shall include some portion of secondary compression, and such time interval shall be the same for each load increment. However, if the "equilibrium" value chosen is other than the 100 % primary consolidation point, a note to this effect should be included with the test results. It should be noted that the second alternative cited above will result in somewhat lower values of the preconsolidation pressure than are obtained when the 100 % primary consolidation points are used.

12. Report

12.1 The report shall include the following information:

12.1.1 Identification and description of the test sample, including whether soil is undisturbed, remolded, compacted, or otherwise prepared,

12.1.2 Initial and final moisture content,

12.1.3 Dry mass and initial and final wet unit weight,

12.1.4 Initial percentage saturation,

12.1.5 Specific gravity of solids or Atterberg Limit gradation data if obtained,

12.1.6 Specimen dimensions,

12.1.7 Condition of test (natural moisture or inundated, pressure at inundation),

12.1.8 Preparation procedure used relative to trimming; state whether specimen was

trimmed, extruded directly into the ring, or tested directly in a ring from a ring-lined sampler,

12.1.9 Plot of log of time or square root of time versus deformation, for those load increments where time-rate readings were taken. For organic or highly micaceous soils, or other soils with appreciable secondary compression, it is highly desirable that log of time plots extending into the secondary compression region be included,

12.1.10 Plot of void ratio versus log of pressure curve or percent compression versus log of pressure curve,

12.1.11 In cases where time rate of consolidation readings have been taken for several load increments, a plot of coefficient of consolidation versus log of average pressure. As an alternative, a plot of log of coefficient of consolidation versus log of average pressure curve may be used. The method used for computing c_v should be noted. If time-rate readings were obtained for only two load increments, simply tabulate the values of c_v versus the average pressure for the increment,

12.1.12 All departures from the procedure outlined, including special loading sequences. For example, it may be desirable to inundate and load the specimen precisely in accordance with the wetting or loading pattern expected in the field in order to best simulate the response. Smaller than standard load increment ratios may be desirable for soils that are highly sensitive or whose response is highly dependent on strain rate.

13. Precision and Accuracy

13.1 Section 5 of this method specifies the sensitivity of the load and deformation measurements. The corresponding accuracy of the applied stress and resultant strain in the specimen can be computed from the specimen dimensions. The accuracy with which the test results can be applied to the field varies from case to case and depends on:

13.1.1 The quality of samples used,

13.1.2 The number of samples tested,

13.1.3 The vertical and horizontal distribution of the samples tested, and

13.1.4 The heterogeneity of the soil profile in the field.

13.2 A statistical analysis that includes both

the sampling program and the laboratory test results is required to assess, in any meaningful way, the accuracy with which the test results apply to the field. In the absence of such an analysis, most engineers assess the applicability of the test results to the field qualitatively by looking at the variation in the test results and the variations in the boring logs. In general, it can be noted that the accuracy of settlement predictions based on consolidation tests increase (on a percentage basis) with the compressibility of the soil.

Standard Test Method for
LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS[1]

This standard is issued under the fixed designation D 4318; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This test method has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This test method covers the determination of the liquid limit, plastic limit, and the plasticity index of soils as defined in Section 3.

1.1.1 Two procedures for preparing test specimens and two procedures for performing the liquid limit are provided as follows:

A Multipoint test using a wet preparation procedure, described in Sections 10.1, 11, and 12.

B Multipoint test using a dry preparation procedure, described in Sections 10.2, 11, and 12.

C One-point test using a wet preparation procedure, described in Sections 13, 14, and 15.

D One-point test using a dry preparation procedure, described in Sections 13, 14, and 15.

The procedure to be used shall be specified by the requesting authority. If no procedure is specified, Procedure A shall be used.

NOTE 1—Prior to the adoption of this test method, a curved grooving tool was specified as part of the apparatus for performing the liquid limit test. The curved tool is not considered to be as accurate as the flat tool described in 6.2 since it does not control the depth of the soil in the liquid limit cup. However, there are some data which indicate that typically the liquid limit is slightly increased when the flat tool is used instead of the curved tool.

1.1.2 The plastic limit test procedure is described in Sections 16, 17, and 18. The plastic limit test is performed on material prepared for the liquid limit test. In effect, there are two procedures for preparing test specimens for the plastic limit test.

1.1.3 The procedure for calculating the plasticity index is given in Section 19.

1.2 The liquid limit and plastic limit of soils (along with the shrinkage limit) are often collectively referred to as the Atterberg limits in recognition of their formation by Swedish soil scientist, A. Atterberg. These limits distinguish the boundaries of the several consistency states of plastic soils.

1.3 As used in this test method, soil is any natural aggregation of mineral or organic materials, mixtures of such materials, or artificial mixtures of aggregates and natural mineral and organic particles.

1.4 The multipoint liquid limit procedure is somewhat more time consuming than the one-point procedure when both are performed by experienced operators. However, the one-point procedure requires the operator to judge when the test specimen is approximately at its liquid limit. In cases where this is not done reliably, the multipoint procedure is as fast as the one-point procedure and provides additional precision due to the information obtained from additional trials. It is particularly recommended that the multipoint procedure be used by inexperienced operators.

1.5 The correlations on which the calculations of the one-point procedure are based may not be valid for certain soils, such as organic soils or

soils from a marine environment. The liquid limit of these soils should therefore be determined by the multipoint procedure (Procedure A).

1.6 The liquid and plastic limits of many soils that have been allowed to dry before testing may be considerably different from values obtained on undried samples. If the liquid and plastic limits of soils are used to correlate or estimate the engineering behavior of soils in their natural moist state, samples should not be permitted to dry before testing unless data on dried samples are specifically desired.

1.7 The composition and concentration of soluble salts in a soil affect the values of the liquid and plastic limits as well as the water content values of soils (see Method D 2216). Special consideration should therefore be given to soils from a marine environment or other sources where high soluble salt concentrations may be present. The degree to which the salts present in these soils are diluted or concentrated must be given consideration if meaningful results are to be obtained.

1.8 Since the tests described herein are performed only on that portion of a soil which passes the 425-μm (No. 40) sieve, the relative contribution of this portion of the soil to the properties of the sample as a whole must be considered when using these tests to evaluate the properties of a soil.

1.9 The values stated in acceptable metric units are to be regarded as the standard. The values given in parentheses are for information only.

1.10 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Applicable Documents

2.1 *ASTM Standards:*
C 702 Methods for Reducing Field Samples of Aggregate to Testing Size[2]
D 75 Practice for Sampling Aggregates[3]
D 420 Recommended Practice for Investigating and Sampling Soil and Rock for Engineering Purposes[4]

D 653 Terms and Symbols Relating to Soil and Rock[4]
D 1241 Specification for Materials for Soil Aggregate Subbase, Base, and Surface Courses[4]
D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[4]
D 2240 Test Method for Rubber Property—Durometer Hardness[5]
D 2487 Test Method for Classification of Soil for Engineering Purposes[4]
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[4]
D 3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes[4]
E 11 Specification for Wire-Cloth Sieves for Testing Purposes[6]
E 319 Methods of Testing Single-Arm Balances[6]
E 898 Method of Testing Top-Loading, Direct-Reading Laboratory Scales and Balances[6]

3. Definitions

3.1 *Atterberg limits*—originally, seven "limits of consistency" of fine-grained soils were defined by Albert Atterberg. In current engineering usage, the term usually refers only to the liquid limit, plastic limit, and in some references, the shrinkage limit.

3.2 *consistency*—the relative ease with which a soil can be deformed.

3.3 *liquid limit (LL)*—the water content, in percent, of a soil at the arbitrarily defined boundary between the liquid and plastic states. This water content is defined as the water content at which a pat of soil placed in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (½ in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of 2 shocks per second.

[2] *Annual Book of ASTM Standards*, Vol 04.02.
[3] *Annual Book of ASTM Standards*, Vols 04.02, 04.03, and 04.08.
[4] *Annual Book of ASTM Standards*, Vol 04.02.
[5] *Annual Book of ASTM Standards*, Vol 09.01.
[6] *Annual Book of ASTM Standards*, Vol 14.02.

NOTE 2—The undrained shear strength of soil at the liquid limit is considered to be 2 ± 0.2 kPa (0.28 psi).

3.4 *plastic limit (PL)*—the water content, in percent, of a soil at the boundary between the plastic and brittle states. The water content at this boundary is the water content at which a soil can no longer be deformed by rolling into 3.2 mm (⅛ in.) in diameter threads without crumbling.

3.5 *plastic soil*—a soil which has a range of water content over which it exhibits plasticity and which will retain its shape on drying.

3.6 *plasticity index (PI)*—the range of water content over which a soil behaves plastically. Numerically, it is the difference between the liquid limit and the plastic limit.

3.7 *liquidity index*—the ratio, expressed as a percentage, of (1) the natural water content of a soil minus its plastic limit, to (2) its plasticity index.

3.8 *activity number (A)*—the ratio of (1) the plasticity index of a soil to (2) the percent by weight of particles having an equivalent diameter smaller than 0.002 mm.

4. Summary of Method

4.1 The sample is processed to remove any material retained on a 425-μm (No. 40) sieve. The liquid limit is determined by performing trials in which a portion of the sample is spread in a brass cup, divided in two by a grooving tool, and then allowed to flow together from the shocks caused by repeatedly dropping the cup in a standard mechanical device. The multipoint liquid limit, Procedures A and B, requires three or more trials over a range of water contents to be performed and the data from the trials plotted or calculated to make a relationship from which the liquid limit is determined. The one-point liquid limit, Procedures C and D, uses the data from two trials at one water content multiplied by a correction factor to determine the liquid limit.

4.2 The plastic limit is determined by alternately pressing together and rolling into a 3.2 mm (⅛ in.) diameter thread a small portion of plastic soil until its water content is reduced to a point at which the thread crumbles and is no longer able to be pressed together and rerolled. The water content of the soil at this stage is reported as the plastic limit.

4.3 The plasticity index is calculated as the difference between the liquid limit and the plastic limit.

5. Significance and Use

5.1 This test method is used as an integral part of several engineering classification systems to characterize the fine-grained fractions of soils (see Test Method D 2487 and Practice D 3282) and to specify the fine-grained fraction of construction materials (see Specification D 1241). The liquid limit, plastic limit, and plasticity index of soils are also used extensively, either individually or together with other soil properties to correlate with engineering behavior such as compressibility, permeability, compactibility, shrink-swell, and shear strength.

5.2 The liquid and plastic limits of a soil can be used with the natural water content of the soil to express its relative consistency or liquidity index and can be used with the percentage finer than 2-μm size to determine its activity number.

5.3 The one-point liquid limit procedure is frequently used for routine classification purposes. When greater precision is required, as when used for the acceptance of a material or for correlation with other test data, the multipoint procedure should be used.

5.4 These methods are sometimes used to evaluate the weathering characteristics of clay-shale materials. When subjected to repeated wetting and drying cycles, the liquid limits of these materials tend to increase. The amount of increase is considered to be a measure of a shale's susceptibility to weathering.

5.5 The liquid limit of a soil containing substantial amounts of organic matter decreases dramatically when the soil is oven-dried before testing. Comparison of the liquid limit of a sample before and after oven-drying can therefore be used as a qualitative measure of organic matter content of a soil.

6. Apparatus

6.1 *Liquid Limit Device*—A mechanical device consisting of a brass cup suspended from a carriage designed to control its drop onto a hard rubber base. A drawing showing the essential features of the device and the critical dimensions is given in Fig. 1. The design of the device may vary provided that the essential functions are

preserved. The device may be operated either by a hand crank or by an electric motor.

6.1.1 *Base*—The base shall be hard rubber having a D Durometer hardness of 80 to 90, and a resilience such that an 8-mm (⁵⁄₁₆-in.) diameter polished steel ball, when dropped from a height of 25 cm (9.84 in.) will have an average rebound of at least 80 % but no more than 90 %. The tests shall be conducted on the finished base with feet attached.

6.1.2 *Feet*—The base shall be supported by rubber feet designed to provide isolation of the base from the work surface and having an A Durometer hardness no greater than 60 as measured on the finished feet attached to the base.

6.1.3 *Cup*—The cup shall be brass and have a weight, including cup hanger, of 185 to 215 g.

6.1.4 *Cam*—The cam shall raise the cup smoothly and continuously to its maximum height, over a distance of at least 180° of cam rotation. The preferred cam motion is a uniformly accelerated lift curve. The design of the cam and follower combination shall be such that there is no upward or downward velocity of the cup when the cam follower leaves the cam.

NOTE 3—The cam and follower design in Fig. 1 is for uniformly accelerated (parabolic) motion after contact and assures that the cup has no velocity at drop off. Other cam designs also provide this feature and may be used. However, if the cam-follower lift pattern is not known, zero velocity at drop off can be assured by carefully filing or machining the cam and follower so that the cup height remains constant over the last 20 to 45° of cam rotation.

6.1.5 *Carriage*—The cup carriage shall be constructed in a way that allows convenient but secure adjustment of the height of drop of the cup to 10 mm (0.394 in.). The cup hanger shall be attached to the carriage by means of a pin which allows removal of the cup and cup hanger for cleaning and inspection.

6.1.6 *Optional Motor Drive*—As an alternative to the hand crank shown in Fig. 1, the device may be equipped with a motor to turn the cam. Such a motor must turn the cam at 2 ±0.1 revolutions per second, and must be isolated from the rest of the device by rubber mounts or in some other way that prevents vibration from the motor being transmitted to the rest of the apparatus. It must be equipped with an ON-OFF switch and a means of conveniently positioning the cam for height of drop adjustments. The results obtained using a motor-driven device

must not differ from those obtained using a manually operated device.

6.2 *Flat Grooving Tool*—A grooving tool having dimensions shown in Fig. 2. The tool shall be made of plastic or noncorroding metal. The design of the tool may vary as long as the essential dimensions are maintained. The tool may, but need not, incorporate the gage for adjusting the height of drop of the liquid limit device.

6.3 *Gage*—A metal gage block for adjusting the height of drop of the cup, having the dimensions shown in Fig. 3. The design of the tool may vary provided the gage will rest securely on the base without being susceptible to rocking, and the edge which contacts the cup during adjustment is straight, at least 10 mm (⅜ in.) wide, and without bevel or radius.

6.4 *Containers*—Small corrosion-resistant containers with snug-fitting lids for water content specimens. Aluminum or stainless steel cans 2.5 cm (1 in.) high by 5 cm (2 in.) in diameter are appropriate.

6.5 *Balance*—A balance readable to at least 0.01 g and having an accuracy of 0.03 g within three standard deviations within the range of use. Within any 15-g range, a difference between readings shall be accurate within 0.01 g (Notes 4 and 5).

NOTE 4—See Methods E 898 and E 319 for an explanation of terms relating to balance performance.

NOTE 5—For frequent use, a top-loading type balance with automatic load indication, readable to 0.01 g, and having an index of precision (standard deviation) of 0.003 or better is most suitable for this method. However, nonautomatic indicating equal-arm analytical balances and some small equal-arm top pan balances having readabilities and sensitivities of 0.002 g or better provide the required accuracy when used with a weight set of ASTM Class 4 (National Bureau of Standards Class P) or better. Ordinary commercial and classroom type balances such as beam balances are not suitable for this method.

6.6 *Storage Container*—A container in which to store the prepared soil specimen that will not contaminate the specimen in any way, and which prevents moisture loss. A porcelain, glass, or plastic dish about 11.4 cm (4½ in.) in diameter and a plastic bag large enough to enclose the dish and be folded over is adequate.

6.7 *Ground Glass Plate*—A ground glass plate at least 30 cm (12 in.) square by 1 cm (⅜ in.) thick for mixing soil and rolling plastic limit threads.

6.8 *Spatula*—A spatula or pill knife having a

blade about 2 cm (¾ in.) wide by about 10 cm (4 in.) long. In addition, a spatula having a blade about 2.5 cm (1 in.) wide and 15 cm (6 in.) long has been found useful for initial mixing of samples.

6.9 *Sieve*—A 20.3 cm (8 in.) diameter, 425-µm (No. 40) sieve conforming to the requirements of Specification E 11 and having a rim at least 5 cm (2 in.) above the mesh. A 2-mm (No. 10) sieve meeting the same requirements may also be needed.

6.10 *Wash Bottle*, or similar container for adding controlled amounts of water to soil and washing fines from coarse particles.

6.11 *Drying Oven*—A thermostatically controlled oven, preferably of the forced-draft type, capable of continuously maintaining a temperature of 110 ±5°C throughout the drying chamber. The oven shall be equipped with a thermometer of suitable range and accuracy for monitoring oven temperature.

6.12 *Washing Pan*—A round, flat-bottomed pan at least 7.6 cm (3 in.) deep, slightly larger at the bottom than a 20.3-cm (8-in.) diameter sieve.

6.13 *Rod* (optional)—A metal or plastic rod or tube 3.2 mm (⅛ in.) in diameter and about 10 cm (4 in.) long for judging the size of plastic limit threads.

7. Materials

7.1 A supply of distilled or demineralized water.

8. Sampling

8.1 Samples may be taken from any location that satisfies testing needs. However, Methods C 702, and Practice D 75, and Recommended Practice D 420 should be used as guides for selecting and preserving samples from various types of sampling operations. Samples which will be prepared using the wet preparation procedure, 10.1, must be kept at their natural water content prior to preparation.

8.2 Where sampling operations have preserved the natural stratification of a sample, the various strata must be kept separated and tests performed on the particular stratum of interest with as little contamination as possible from other strata. Where a mixture of materials will be used in construction, combine the various components in such proportions that the resultant sample represents the actual construction case.

8.3 Where data from this test method are to be used for correlation with other laboratory or field test data, use the same material as used for these tests where possible.

8.4 Obtain a representative portion from the total sample sufficient to provide 150 to 200 g of material passing the 425-µm (No. 40) sieve. Free flowing samples may be reduced by the methods of quartering or splitting. Cohesive samples shall be mixed thoroughly in a pan with a spatula, or scoop and a representative portion scooped from the total mass by making one or more sweeps with a scoop through the mixed mass.

9. Calibration of Apparatus

9.1 *Inspection of Wear:*

9.1.1 *Liquid Limit Device*—Determine that the liquid limit device is clean and in good working order. The following specific points should be checked:

9.1.1.1 *Wear of Base*—The spot on the base where the cup makes contact should be worn no greater than 10 mm (⅜ in.) in diameter. If the wear spot is greater than this, the base can be machined to remove the worn spot provided the resurfacing does not make the base thinner than specified in 6.1 and the other dimensional relationships are maintained.

9.1.1.2 *Wear of Cup*—The cup must be replaced when the grooving tool has worn a depression in the cup 0.1 mm (0.004 in.) deep or when the edge of the cup has been reduced to half its original thickness. Verify that the cup is firmly attached to the cup hanger.

9.1.1.3 *Wear of Cup Hanger*—Verify that the cup hanger pivot does not bind and is not worn to an extent that allows more than 3-mm (⅛-in.) side-to-side movement of the lowest point on the rim.

9.1.1.4 *Wear of Cam*—The cam shall not be worn to an extent that the cup drops before the cup hanger (cam follower) loses contact with the cam.

9.1.2 *Grooving Tools*—Inspect grooving tools for wear on a frequent and regular basis. The rapidity of wear depends on the material from which the tool is made and the types of soils being tested. Sandy soils cause rapid wear of grooving tools; therefore, when testing these materials, tools should be inspected more frequently than for other soils. Any tool with a tip width greater than 2.1 mm must not be used. The depth

of the tip of the grooving tool must be 7.9 to 8.1 mm.

NOTE 6—The width of the tip of grooving tools is conveniently checked using a pocket-sized measuring magnifier equipped with a millimetre scale. Magnifiers of this type are available from most laboratory supply companies. The depth of the tip of grooving tools can be checked using the depth measuring feature of vernier calipers.

9.2 *Adjustment of Height of Drop*—Adjust the height of drop of the cup so that the point on the cup that comes in contact with the base rises to a height of 10 ±0.2 mm. See Fig. 4 for proper location of the gage relative to the cup during adjustment.

NOTE 7—A convenient procedure for adjusting the height of drop is as follows: place a piece of masking tape across the outside bottom of the cup parallel with the axis of the cup hanger pivot. The edge of the tape away from the cup hanger should bisect the spot on the cup that contacts the base. For new cups, placing a piece of carbon paper on the base and allowing the cup to drop several times will mark the contact spot. Attach the cup to the device and turn the crank until the cup is raised to its maximum height. Slide the height gage under the cup from the front, and observe whether the gage contacts the cup or the tape. See Fig. 4. If the tape and cup are both contacted, the height of drop is approximately correct. If not, adjust the cup until simultaneous contact is made. Check adjustment by turning the crank at 2 revolutions per second while holding the gage in position against the tape and cup. If a ringing or clicking sound is heard without the cup rising from the gage, the adjustment is correct. If no ringing is heard or if the cup rises from the gage, readjust the height of drop. If the cup rocks on the gage during this checking operation, the cam follower pivot is excessively worn and the worn parts should be replaced. Always remove tape after completion of adjustment operation.

MULTIPOINT LIQUID LIMIT—PROCEDURES A AND B

10. Preparation of Test Specimens

10.1 *Wet Preparation*—Except where the dry method of specimen preparation is specified (10.2), prepare specimens for test as described in the following sections.

10.1.1 *Samples Passing the 425-μm (No. 40) Sieve*—When by visual and manual procedures it is determined that the sample has little or no material retained on a 425-μm (No. 40) sieve, prepare a specimen of 150 to 200 g by mixing thoroughly with distilled or demineralized water on the glass plate using the spatula. If desired, soak soil in a storage dish with small amount of water to soften the soil before the start of mixing.

Adjust the water content of the soil to bring it to a consistency that would require 25 to 35 blows of the liquid limit device to close the groove (Note 8). If, during mixing, a small percentage of material is encountered that would be retained on a 425-μm (No. 40) sieve, remove these particles by hand, if possible. If it is impractical to remove the coarser material by hand, remove small percentages (less than about 15 %) of coarser material by working the specimen through a 425-μm (No. 40) sieve using a piece of rubber sheeting, rubber stopper, or other convenient device provided the operation does not distort the sieve or degrade material that would be retained if the washing method described in 10.1.2 were used. If larger percentages of coarse material are encountered during mixing, or it is considered impractical to remove the coarser material by the methods just described, wash the sample as described in 10.1.2. When the coarse particles found during mixing are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425-μm (No. 40) sieve, but remove by hand or by washing. Place the mixed soil in the storage dish, cover to prevent loss of moisture, and allow to stand for at least 16 h (overnight). After the standing period and immediately before starting the test, thoroughly remix the soil.

NOTE 8—The time taken to adequately mix a soil will vary greatly, depending on the plasticity and initial water content. Initial mixing times of more than 30 — in may be needed for stiff, fat clays.

10.1.2 *Samples Containing Material Retained on a 425-μm (No. 40) Sieve:*

10.1.2.1 Select a sufficient quantity of soil at natural water content to provide 150 to 200 g of material passing the 425-μm (No. 40) sieve. Place in a pan or dish and add sufficient water to cover the soil. Allow to soak until all lumps have softened and the fines no longer adhere to the surfaces of the coarse particles (Note 9).

NOTE 9—In some cases, the cations of salts present in tap water will exchange with the natural cations in the soil and significantly alter the test results should tap water be used in the soaking and washing operations. Unless it is known that such cations are not present in the tap water, distilled or demineralized water should be used. As a general rule, water containing more than 100 mg/L of dissolved solids should not be used for washing operations.

10.1.2.2 When the sample contains a large percentage of material retained on the 425-μm

(No. 40) sieve, perform the following washing operation in increments, washing no more than 0.5 kg (1 lb) of material at one time. Place the 425-μm (No. 40) sieve in the bottom of the clean pan. Pour the soil water mixture onto the sieve. If gravel or coarse sand particles are present, rinse as many of these as possible with small quantities of water from a wash bottle, and discard. Alternatively, pour the soil water mixture over a 2-mm (No. 10) sieve nested atop the 425-μm (No. 40) sieve, rinse the fine material through and remove the 2-mm (No. 10) sieve. After washing and removing as much of the coarser material as possible, add sufficient water to the pan to bring the level to about 13 mm (½ in.) above the surface of the 425-μm (No. 40) sieve. Agitate the slurry by stirring with the fingers while raising and lowering the sieve in the pan and swirling the suspension so that fine material is washed from the coarser particles. Disaggregate fine soil lumps that have not slaked by gently rubbing them over the sieve with the fingertips. Complete the washing operation by raising the sieve above the water surface and rinsing the material retained with a small amount of clean water. Discard material retained on the 425-μm (No. 40) sieve.

10.1.2.3 Reduce the water content of the material passing the 425-μm (No. 40) sieve until it approaches the liquid limit. Reduction of water content may be accomplished by one or a combination of the following methods: (a) exposing to the air currents at ordinary room temperature, (b) exposing to warm air currents from a source such as an electric hair dryer, (c) filtering in a Buckner funnel or using filter candles, (d) decanting clear water from surface of suspension, or (e) draining in a colander or plaster of paris dish lined with high retentivity, high wet-strength filter paper.[7] If a plaster of paris dish is used, take care that the dish never becomes sufficiently saturated that it fails to actively absorb water into its surface. Thoroughly dry dishes between uses. During evaporation and cooling, stir the sample often enough to prevent overdrying of the fringes and soil pinnacles on the surface of the mixture. For soil samples containing soluble salts, use a method of water reduction such as a or b that will not eliminate the soluble salts from the test specimen.

10.1.2.4 Thoroughly mix the material passing the 425-μm (No. 40) sieve on the glass plate using the spatula. Adjust the water content of the mixture, if necessary, by adding small increments of

distilled or demineralized water or by allowing the mixture to dry at room temperature while mixing on the glass plate. The soil should be at a water content that will result in closure of the groove in 25 to 35 blows. Return the mixed soil to the mixing dish, cover to prevent loss of moisture, and allow to stand for at least 16 h. After the standing period, and immediately before starting the test, remix the soil thoroughly.

10.2 *Dry Preparation:*

10.2.1 Select sufficient soil to provide 150 to 200 g of material passing the 425-μm (No. 40) sieve after processing. Dry the sample at room temperature or in an oven at a temperature not exceeding 60°C until the soil clods will pulverize readily. Disaggregation is expedited if the sample is not allowed to completely dry. However, the soil should have a dry appearance when pulverized. Pulverize the sample in a mortar with a rubber tipped pestal or in some other way that does not cause breakdown of individual grains. When the coarse particles found during pulverization are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425-μm (No. 40) sieve, but remove by hand or other suitable means, such as washing.

10.2.2 Separate the sample on a 425-μm (No. 40) sieve, shaking the sieve by hand to assure thorough separation of the finer fraction. Return the material retained on the 425-μm (No. 40) sieve to the pulverizing apparatus and repeat the pulverizing and sieving operations as many times as necessary to assure that all finer material has been disaggregated and material retained on the 425-μm (No. 40) sieve consists only of individual sand or gravel grains.

10.2.3 Place material remaining on the 425-μm (No. 40) sieve after the final pulverizing operations in a dish and soak in a small amount of water. Stir the soil water mixture and pour over the 425-μm (No. 40) sieve, catching the water and any suspended fines in the washing pan. Pour this suspension into a dish containing the dry soil previously sieved through the 425-μm (No. 40) sieve. Discard material retained on the 425-μm (No. 40) sieve.

10.2.4 Adjust the water content as necessary by drying as described in 10.1.2.3 or by mixing on the glass plate, using the spatula while adding increments of distilled or demineralized water,

---

[7] S and S 595 filter paper, available in 32-cm circles, has proven satisfactory.

until the soil is at a water content that will result in closure of the groove in 25 to 35 blows.

10.2.5 Put soil in the storage dish, cover to prevent loss of moisture and allow to stand for at least 16 h. After the standing period, and immediately before starting the test, thoroughly remix the soil (Note 8).

11. Procedure

11.1 Place a portion of the prepared soil in the cup of the liquid limit device at the point where the cup rests on the base, squeeze it down, and spread it into the cup to a depth of about 10 mm at its deepest point, tapering to form an approximately horizontal surface. Take care to eliminate air bubbles from the soil pat but form the pat with as few strokes as possible. Heap the unused soil on the glass plate and cover with the inverted storage dish or a wet towel.

11.2 Form a groove in the soil pat by drawing the tool, beveled edge forward, through the soil on a line joining the highest point to the lowest point on the rim of the cup. When cutting the groove, hold the grooving tool against the surface of the cup and draw in an arc, maintaining the tool perpendicular to the surface of the cup throughout its movement. See Fig. 5. In soils where a groove cannot be made in one stroke without tearing the soil, cut the groove with several strokes of the grooving tool. Alternatively, cut the groove to slightly less than required dimensions with a spatula and use the grooving tool to bring the groove to final dimensions. Exercise extreme care to prevent sliding the soil pat relative to the surface of the cup.

11.3 Verify that no crumbs of soil are present on the base or the underside of the cup. Lift and drop the cup by turning the crank at a rate of 1.9 to 2.1 drops per second until the two halves of the soil pat come in contact at the bottom of the groove along a distance of 13 mm (½ in.). See Fig. 6.

NOTE 10—Use the end of the grooving tool, Fig. 2, or a scale to verify that the groove has closed 13 mm (½ in.).

11.4 Verify that an air bubble has not caused premature closing of the groove by observing that both sides of the groove have flowed together with approximately the same shape. If a bubble has caused premature closing of the groove, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving

operation and repeat 11.1 to 11.3. If the soil slides on the surface of the cup, repeat 11.1 through 11.3 at a higher water content. If, after several trials at successively higher water contents, the soil pat continues to slide in the cup or if the number of blows required to close the groove is always less than 25, record that the liquid limit could not be determined, and report the soil as nonplastic without performing the plastic limit test.

11.5 Record the number of drops, N, required to close the groove. Remove a slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right angles to the groove and including that portion of the groove in which the soil flowed together, place in a weighed container, and cover.

11.6 Return the soil remaining in the cup to the glass plate. Wash and dry the cup and grooving tool and reattach the cup to the carriage in preparation for the next trial.

11.7 Remix the entire soil specimen on the glass plate adding distilled water to increase the water content of the soil and decrease the number of blows required to close the groove. Repeat 11.1 through 11.6 for at least two additional trials producing successively lower numbers of blows to close the groove. One of the trials shall be for a closure requiring 25 to 35 blows, one for closure between 20 and 30 blows, and one trial for a closure requiring 15 to 25 blows.

11.8 Determine the water content, W_N, of the soil specimen from each trial in accordance with Method D 2216. Make all weighings on the same balance. Initial weighings should be performed immediately after completion of the test. If the test is to be interrupted for more than about 15 min, the specimens already obtained should be weighed at the time of the interruption.

12. Calculations

12.1 Plot the relationship between the water content, W_N, and the corresponding number of drops, N, of the cup on a semilogarithmic graph with the water content as ordinates on the arithmetical scale, and the number of drops as abscissas on the logarithmic scale. Draw the best straight line through the three or more plotted points.

12.2 Take the water content corresponding to the intersection of the line with the 25-drop abscissa as the liquid limit of the soil. Computa-

tional methods may be substituted for the graphical method for fitting a straight line to the data and determining the liquid limit.

ONE-POINT LIQUID LIMIT—PROCEDURES C AND D

13. Preparation of Test Specimens

13.1 Prepare the specimen in the same manner as described in Section 10, except that at mixing, adjust the water content to a consistency requiring 20 to 30 drops of the liquid limit cup to close the groove.

14. Procedure

14.1 Proceed as described in 11.1 through 11.5 except that the number of blows required to close the groove shall be 20 to 30. If less than 20 or more than 30 blows are required, adjust the water content of the soil and repeat the procedure.

14.2 Immediately after removing a water content specimen as described in 11.5, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving and water content sampling operations. Repeat 11.2 through 11.5, and, if the second closing of the groove requires the same number of drops or no more than two drops difference, secure another water content specimen. Otherwise, remix the entire specimen and repeat.

NOTE 11—Excessive drying or inadequate mixing will cause the number of blows to vary.

14.3 Determine water contents of specimens as described in 11.8.

15. Calculations

15.1 Determine the liquid limit for each water content specimen using one of the following equations:

$$LL = W_N \left(\frac{N}{25}\right)^{0.121} \text{ or}$$

$$LL = K(W_N)$$

where:

N = the number of blows causing closure of the groove at water content,

W_N = water content, and

K = a factor given in Table 1.

The liquid limit is the average of the two trial liquid limit values.

15.2 If the difference between the two trial

liquid limit values is greater than one percentage point, repeat the test.

PLASTIC LIMIT

16. Preparation of Test Specimen

16.1 Select a 20-g portion of soil from the material prepared for the liquid limit test, either after the second mixing before the test, or from the soil remaining after completion of the test. Reduce the water content of the soil to a consistency at which it can be rolled without sticking to the hands by spreading and mixing continuously on the glass plate. The drying process may be accelerated by exposing the soil to the air current from an electric fan, or by blotting with paper that does not add any fiber to the soil, such as hard surface paper toweling or high wet strength filter paper.

17. Procedure

17.1 From the 20-g mass, select a portion of 1.5 to 2.0 g. Form the test specimen into an ellipsoidal mass. Roll this mass between the palm or fingers and the ground-glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length (Note 12). The thread shall be further deformed on each stroke so that its diameter is continuously reduced and its length extended until the diameter reaches 3.2 ±0.5 mm (0.125 ±.020 in.), taking no more than 2 min (Note 13). The amount of hand or finger pressure required will vary greatly, according to the soil. Fragile soils of low plasticity are best rolled under the outer edge of the palm or at the base of the thumb.

NOTE 12—A normal rate of rolling for most soils should be 80 to 90 strokes per minute, counting a stroke as one complete motion of the hand forward and back to the starting position. This rate of rolling may have to be decreased for very fragile soils.

NOTE 13—A 3.2-mm (⅛-in.) diameter rod or tube is useful for frequent comparison with the soil thread to ascertain when the thread has reached the proper diameter, especially for inexperienced operators.

17.1.1 When the diameter of the thread becomes 3.2 mm, break the thread into several pieces. Squeeze the pieces together, knead between the thumb and first finger of each hand, reform into an ellipsoidal mass, and reroll. Continue this alternate rolling to a thread 3.2 mm in diameter, gathering together, kneading and rerolling, until the thread crumbles under the pres-

sure required for rolling and the soil can no longer be rolled into a 3.2-mm diameter thread (See Fig. 7). It has no significance if the thread breaks into threads of shorter length. Roll each of these shorter threads to 3.2 mm in diameter. The only requirement for continuing the test is that they are able to be reformed into an ellipsoidal mass and rolled out again. The operator shall at no time attempt to produce failure at exactly 3.2 mm diameter by allowing the thread to reach 3.2 mm, then reducing the rate of rolling or the hand pressure, or both, while continuing the rolling without further deformation until the thread falls apart. It is permissible, however, to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal mass nearer to the required 3.2-mm final diameter. If crumbling occurs when the thread has a diameter greater than 3.2 mm, this shall be considered a satisfactory end point, provided the soil has been previously rolled into a thread 3.2 mm in diameter. Crumbling of the thread will manifest itself differently with the various types of soil. Some soils fall apart in numerous small aggregations of particles, others may form an outside tubular layer that starts splitting at both ends. The splitting progresses toward the middle, and finally, the thread falls apart in many small platy particles. Fat clay soils require much pressure to deform the thread, particularly as they approach the plastic limit. With these soils, the thread breaks into a series of barrel-shaped segments about 3.2 to 9.5 mm (⅛ to ⅜ in.) in length.

17.2 Gather the portions of the crumbled thread together and place in a weighed container. Immediately cover the container.

17.3 Select another 1.5 to 2.0 g portion of soil from the original 20-g specimen and repeat the operations described in 17.1 and 17.2 until the container has at least 6 g of soil.

17.4 Repeat 17.1 through 17.3 to make another container holding at least 6 g of soil. Determine the water content, in percent, of the soil contained in the containers in accordance with Method D 2216. Make all weighings on the same balance.

NOTE 14—The intent of performing two plastic limit trials is to verify the consistency of the test results. It is acceptable practice to perform only one plastic limit trial when the consistency in the test results can be confirmed by other means.

18. Calculations

18.1 Compute the average of the two water contents. If the difference between the two water contents is greater than two percentage points, repeat the test. The plastic limit is the average of the two water contents.

PLASTICITY INDEX

19. Calculations

19.1 Calculate the plasticity index as follows:

$$PI = LL - PL$$

where:
LL = the liquid limit,
PL = the plastic limit.

Both LL and PL are whole numbers. If either the liquid limit or plastic limit could not be determined, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP.

20. Report

20.1 Report the following information:
20.1.1 Sample identifying information,
20.1.2 Any special specimen selection process used, such as removal of sand lenses from undisturbed sample,
20.1.3 Report sample as airdried if the sample was airdried before or during preparation,
20.1.4 Liquid limit, plastic limit, and plasticity index to the nearest whole number and omitting the percent designation. If the liquid limit or plastic limit tests could not be performed, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP,
20.1.5 An estimate of the percentage of sample retained on the 425-μm (No. 40) sieve, and
20.1.6 Procedure by which liquid limit was performed, if it differs from the multipoint method.

21. Precision and Bias

21.1 No interlaboratory testing program has as yet been conducted using this test method to determine multilaboratory precision.

21.2 The within laboratory precision of the results of tests performed by different operators at one laboratory on two soils using Procedure A for the liquid limit is shown in Table 2.

TABLE 1 Factors for Obtaining Liquid Limit from Water Content and Number of Drops Causing Closure of Groove

N (Number of Drops)	K (Factor for Liquid Limit)
20	0.974
21	0.979
22	0.985
23	0.990
24	0.995
25	1.000
26	1.005
27	1.009
28	1.014
29	1.018
30	1.022

TABLE 2 Within Laboratory Precision for Liquid Limit

	Average Value, $\bar{x}$	Standard Deviation, s
Soil A:		
PL	21.9	1.07
LL	27.9	1.07
Soil B:		
PL	20.1	1.21
LL	32.6	0.95

DIMENSIONS

LETTER	A△	B△	C△	E△	F	G	H	J△	K△	L△	M△
MM	54 ± 0.5	2 ± 0.1	27 ± 0.5	56 ± 2.0	32	10	16	60 ± 1.0	50 ± 2.0	150 ± 2.0	125 ± 2.0

LETTER	N	P	R	T	U△	V	W	Z
MM	24	28	24	45	47 ± 1.0	3.8	13	6.5

△ ESSENTIAL DIMENSIONS

CAM ANGLE DEGREES	CAM RADIUS
0	0.742 R
30	0.753 R
60	0.764 R
90	0.773 R
120	0.784 R
150	0.796 R
180	0.818 R
210	0.854 R
240	0.901 R
270	0.945 R
300	0.974 R
330	0.995 R
360	1.000 R

V DIAMETER CRS OR BRASS PIN

SPHERICAL RADIUS A

B

Z SPHERICAL RADIUS

HARD RUBBER BASE CONFORMING TO SPECIFICATION IN 6.1.1

SOFT RUBBER CONFORMING TO SPECIFICATION IN 6.1.2
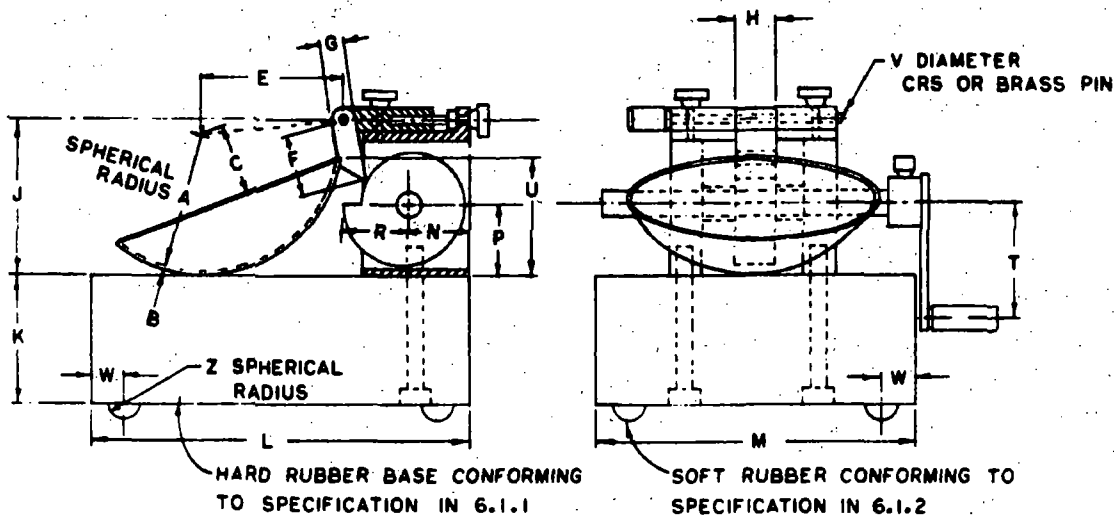
FIG. 1 Hand-Operated Liquid Limit Device

D 4318

774

775

DIMENSIONS

LETTER	A△	B△	C△	D△	E△	F△
MM	2 ± 0.1	11 ± 0.2	40 ± 0.5	8 ± 0.1	50 ± 0.5	2 ± 0.1

LETTER	G	H	J	K△	L△	N
MM	10 MINIMUM	13	60	10 ± 0.05	60 DEG ± 1 DEG	20

△ ESSENTIAL DIMENSIONS

□ BACK AT LEAST 15 MM FROM TIP

NOTE : DIMENSION A SHOULD BE 1.9-2.0 AND DIMENSION D SHOULD BE 8.0-8.1 WHEN NEW TO ALLOW FOR ADEQUATE SERVICE LIFE

E RADIUS

SECTION
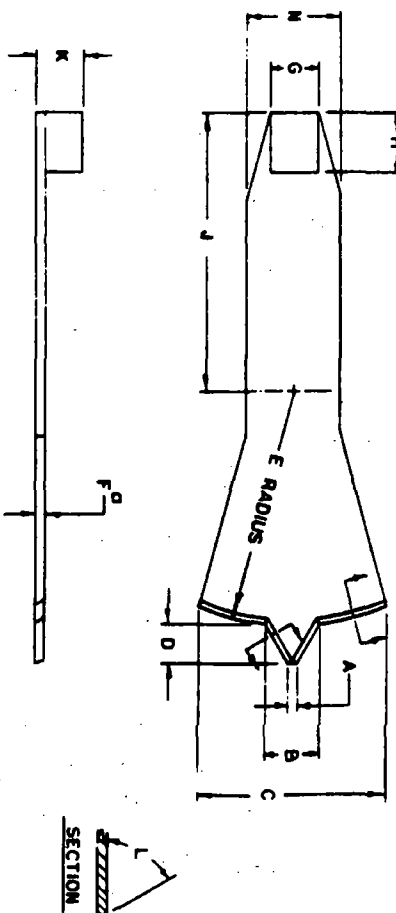
FIG. 2 Grooving Tool (Optional Height-of-Drop Gage Attached)

FIG. 3 Height of Drop Gage
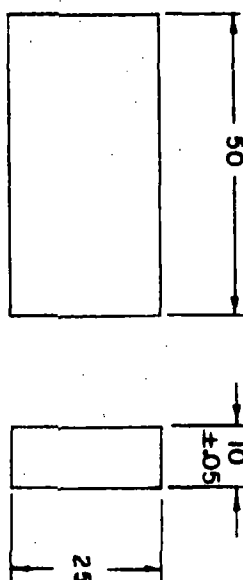
DIMENSIONS IN MILLIMETRES
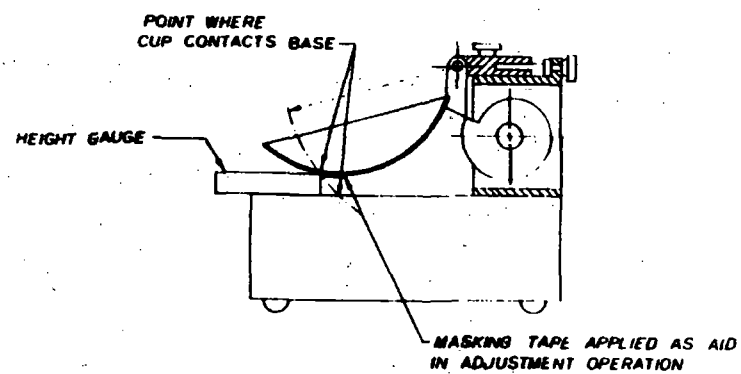
FIG. 4 Calibration for Height of Drop
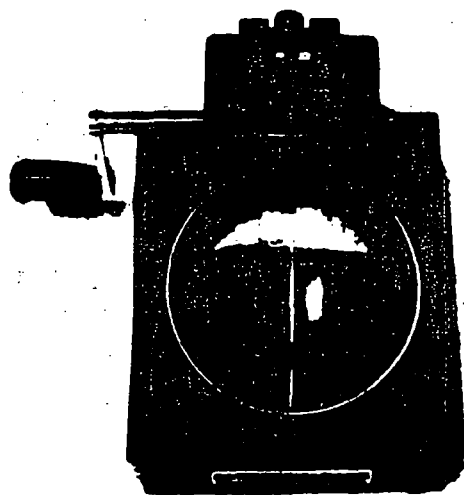
FIG. 5 Grooved Soil Pat in Liquid Limit Device
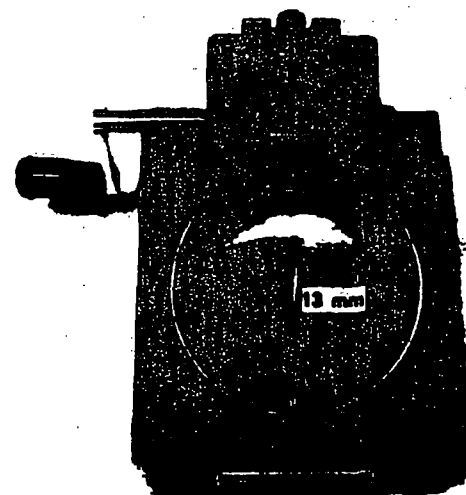
FIG. 6 Soil Pat After Groove Has Closed

APPENDIX D

SOIL BORING LOGS

CanonieEnvironmental

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SAMPLE

No: (Number) Soil samples are numbered consecutively from the ground surface. Core samples are numbered consecutively from the first core run.

Type: A= Auger Cuttings   CR= Core Run   MS= Modified Spoon   PB= Pitcher Barrel
PT= Piston Tube   ST= Shelby Tube   SS= Split Spoon (2" O.D.)   WC= Wash Cuttings

Interval: The depth of sampling interval in feet below ground surface.

BLOW COUNT

The number of blows required to drive a 2-inch O.D. split-spoon sampler with a 140 pound hammer falling 30-inches. When appropriate, the sampler is driven 18 inches and blow counts are reported for each 6-inch interval. The sum of blow counts for the last two 6-inch intervals is designated as the standard penetration resistance (N) expressed as blows per foot.

RECOVERY IN INCHES

The length of sample recovered by the sampling device.

U.S.C.S. SOIL TYPE

The Unified Soil Classification System symbol for recovered soil samples determined by visual examination or laboratory tests. Refer to ASTM D2487-69 for a detailed description of procedure and symbols. Underlined symbols denote classifications based on laboratory tests (ie: **ML**), all others are based on visual classification only.

PERCENT MOISTURE

Natural moisture content of sample expressed as percent of dry weight.

qu, TSF

Unconfined compressive strength in tons per square foot obtained by Hand Penetrometer. Laboratory compression test values are indicated by underlining.

CONTACT DEPTH

The contact depth between soil layers is interpreted from significant changes in recovered samples and observations during drilling. Actual changes between soil layers often occur gradationally and the contact depths shown on the boring logs should be considered as approximate.

SOIL DESCRIPTION AND REMARKS

Soil descriptions include consistency or density, color, predominant soil types, and modifying constituents.

| COHESIVE SOILS			COHESIONLESS SOILS	
Consistency	qu (TSF)	Blows/Ft.	Density	Blows Per Foot
Very Soft	less than 0.25	0-1	Very Loose	4 or less
Soft	0.25 to 0.50	2-4	Loose	5 to 10
Medium Stiff	0.50 to 1.00	5-8	Medium Dense	11 to 30
Stiff	1.00 to 2.00	9-15	Dense	31 to 50
Very Stiff	2.00 to 4.00	15-30	Very Dense	over 50
Hard	more than 4.00	Over 30		

PARTICLE SIZE DESCRIPTION

Boulder =   Larger than 12 inches.
Cobble =   3 to 12 inches.
Gravel =   0.187 to 3 inches.
Sand =   0.074 mm to 4.76 mm.
Silt and Clay = Smaller than 0.074 mm.

DEFINITION OF TERMS

Trace =   5 to 12 percent by weight.
Some =   12 to 30 percent by weight.
And =   Approximately equal fractions.
( )=   Driller's observation.

PIEZO.

(Piezometer) Screened interval of the piezometer installation is denoted by cross-hatching.

GENERAL NOTE

The boring logs and related information depict subsurface conditions only at the specified locations and date indicated. Soil conditions and water levels at other locations may differ from conditions occurring at these boring locations. Also the passage of time may result in a change in the conditions at these boring locations.

SOIL TEST BORING REFUSAL

Defined as any material causing a blow count greater than 50 blows/6 inches. Such material may include bedrock, "floating" rock slabs, boulders, dense gravel seams, or cemented soils. Refusal is usually indicated in fractional notation showing number of blows as the numerator and inches of penetration as the denominator.

Rev. 1-88

Canonie

Boring
Log

PROJECT No. _____

BORING No. _____

LOGGED BY _____

PAGE _____ OF _____

PROJECT NAME _____

BORING LOCATION _____ SURFACE ELEV. _____

DRILLER _____ DATE: START _____ FINISH _____

DEPTH	SAMPLE				BLOW COUNT			RECOVERY IN INCHES	U.S.C.S. SOIL TYPE	PERCENT MOISTURE	qu TSF	CONTACT DEPTH	SOIL DESCRIPTION AND REMARKS	PIEZO.
	No.	TYPE	INTERVAL		0	6	12							
			FROM	TO	6	12	18							

Rev. 2-86

APPENDIX E

BOTTOM SAMPLING DREDGE

Bottom Sampling Dredge

This grab type **Dredge** features flow through design for low drag and good descent ability. Positive acting jaw and lid control system. An excellent tool for obtaining quantitive and qualitative sampling of soft river, stream and lake bottoms. Optional **Operating Handle** allows shallow sampling by hand. 430-350 **Bottom Sampling Dredge** comes complete with polyurethane finished marine plywood carrying case, dredge, messenger, 100' sounding line, and screened wash bucket.

Features
● One man operation.

Specifications

Materials.	Solid brass with stainless steel springs and cables
Chamber Volume	216 cubic inches (3450 cm³)
Chamber Dimensions.	6" x 6" x 6" (152mm x 152mm x 152mm)
Sounding Line.	Nylon
Dimensions.	13" x 15 : " x 15 : " (33cm x 39cm x 39cm) (carrying case)

Models
430-350. Bottom Sampling Dredge.

Weights
Net 20 lbs. (9 kg); Shpg. 28 lbs. (13 kg).

Accessories Options
430-351. Operating Handle. 5'.
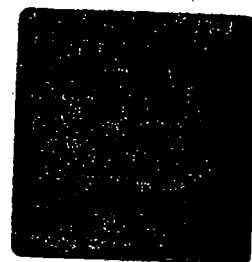
APPENDIX F

ROCK CORE LOGS

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CORING DATA

SIZE: The nominal diameter of rock core is designated by:

BQ= 36.5 mm (1.432 inches)	AW= 30.1 mm (1.185 inches)
NQ= 47.6 mm (1.875 inches)	BW= 42.0 mm (1.655 inches)
HQ= 63.5 mm (2.500 inches)	NW= 54.7 mm (2.155 inches)
PQ= 101.6 mm (4.0 inches)	NX= 54.0 mm (2.125 inches)

PRESS., PSI: Denotes hydraulic down pressure in pounds per square inch.

RATE, FPM: Denotes drilling penetration rate in feet per minute.

% CR: (Percent Core Recovery) The length of recovered core divided by the length of core run and expressed as a whole percent.

LOSS: Graphic zone of lost core (solid) or significant drill water losses (cross-hatched).

DISCONTINUITIES

RQD: (Rock Quality Designation) The total length of recovered rock core pieces, 4 inches or longer divided by the length of core run and expressed as a whole percent. Mechanical breaks during sampling are considered as unbroken core.

FPF: (Fractures per Foot) The average number of separations of all types (including mechanical breakage during sampling) per foot of recovered core.

JOINTS: Natural separations usually inclined to and crossing the bedding planes. Joint location and orientation is denoted by angular dip (degrees) with respect to assumed horizontal.

h= horizontal joint, v= vertical joint, s= slickensided joint

Joint filling materials are denoted by:
cl= clay   Ca= calcite
py= pyrite   Fe= iron oxide (rusty)

Joint spacing is denoted by:
vc= very close (less than 2 inches)
c= close (2 inches to 1 foot)
mc= moderately close (1 foot to 3 feet)
w= wide (3 feet to 10 feet)
vw= very wide (greater than 10 feet)

BEDDING

Bedding planes are approximately horizontal unless otherwise stated. Notations include only actual separations (natural and mechanical) on bedding planes.

Spacing of bedding separations is denoted by:
TT= very thin (less than 2 inches)
TN= thin (2 inches to 1 foot)
MD= medium (1 foot to 3 feet)
TK= thick (3 feet to 10 feet)
VT= very thick (greater than 10 feet)

Condition of bedding separation is denoted as:
o= open   s= stained
t= tight   m= mineralized
cl= clay filled

HARDNESS

VH= (very hard) Cannot be scratched with knife. Breaks under several strong hammer blows with very resistant sharp edges.

H= (hard) Can be scratched with knife with difficulty. Breaks under one or two strong hammer blows with resistant sharp edges.

MH= (moderately hard) Can be scratched with knife. Breaks easily under single hammer blow with crumbly edges.

S= (soft) Can be easily scratched or grooved with knife. Breaks under pressure of pressed hammer.

VS= (very soft) Can be carved with knife or scratched with fingernail. Breaks under finger pressure.

STRENGTH TESTS

Qu: Unconfined compressive strength in tons per square foot.

Is: Diametrically loaded point load strength index in pounds per square inch. Parentheses indicate axially loaded samples.

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Rock Core Log

PROJECT No._____

BORING No._____

PAGE ____ OF ____

PROJECT NAME_____

BORING LOCATION_____ SURFACE ELEV._____

DRILLER_____ DATE START_____ FINISH_____

| DEPTH | CORE | | BOX NO. | CORE DATA | | | | | DISCONTINUITIES | | | BEDDING | HARDNESS | DESCRIPTION AND REMARKS | STRENGTH TESTS | | | |
	NO.	LEN.		SIZE	PSI	FPM	% C.R.	LOSS	RQD	FPF	JOINT				Qu TSF	Is PSI		

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APPENDIX G

OBSERVATION WELL DIAGRAMS

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PROJECT No. _____

WELL No. _____

_____

PROJECT NAME _____

BORING LOCATION _____ DATE _____ BY _____

EL.
DEPTH ———————— GROUND SURFACE

EL.
DEPTH ———————— TOP OF SEAL

EL.
DEPTH ———————— TOP OF BACKFILL

EL.
DEPTH ———————— TOP OF SCREEN

EL.
DEPTH ———————— BOTTOM OF SCREEN

EL.
DEPTH ———————— BOTTOM OF BORING
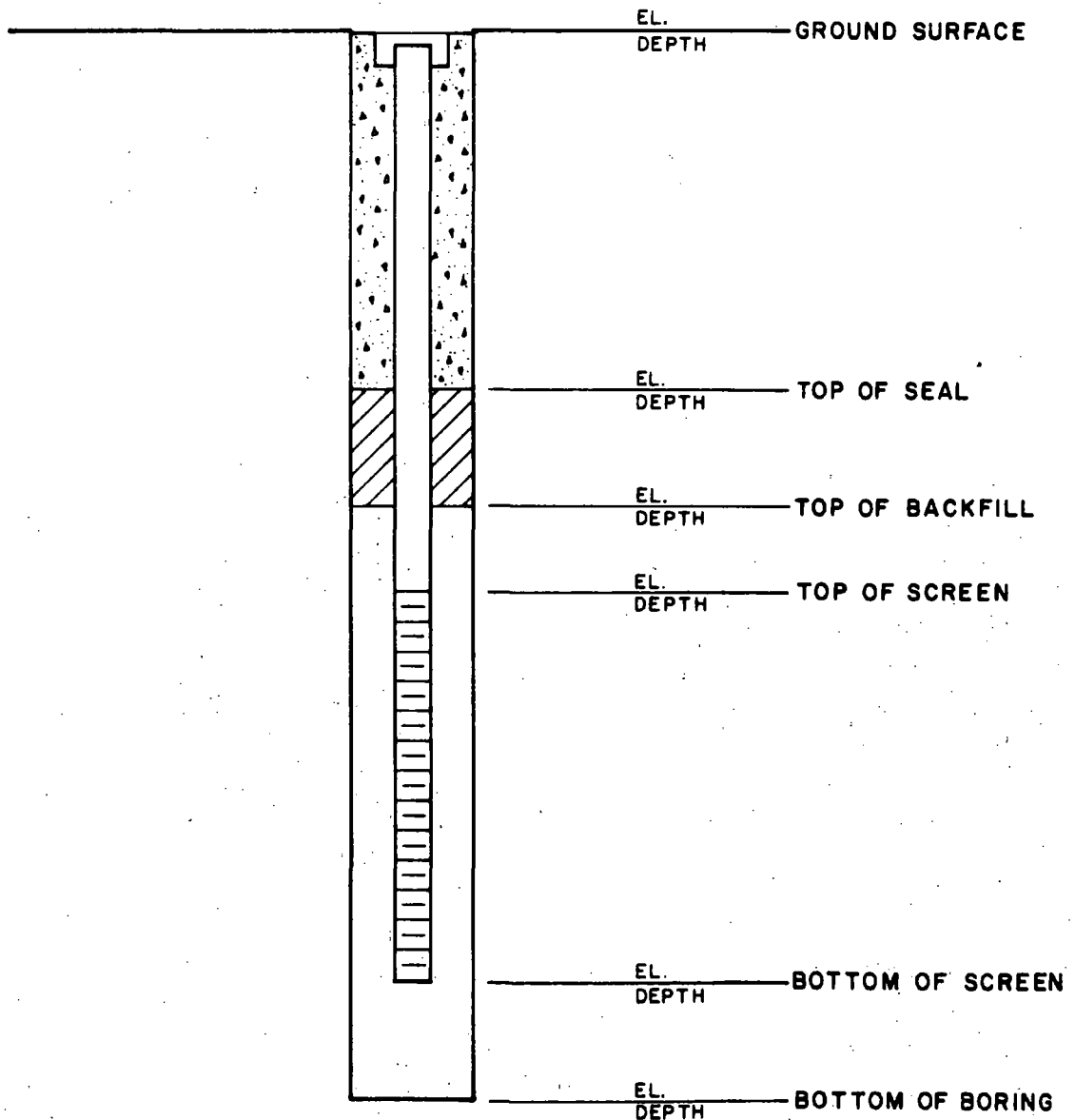
NOTES:
1. NOT DRAWN TO SCALE.
2. SEE BORING LOG
   DETAILED SOIL DESCRIPTION.

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Observation Well Details

PROJECT No. __86-059__

WELL No. _____

PROJECT NAME ____WAUKEGAN HARBOR_____

BORING LOCATION _____ DATE _____ BY _____

LOCKING STEEL CAP

PVC CAP

4" DIA. STEEL PIPE

3'-0"

GROUND SURFACE

CONCRETE

TOP OF SEAL

1" DIA. SCH 80
BLANK PVC PIPE

VOLCLAY GROUT

TOP OF BACKFILL

TOP OF SCREEN

0.010" SLOT
1" DIA. SCH 80
PVC SCREEN

NATURAL WELL-GRADED SAND BACKFILL

BOTTOM OF SCREEN

BOTTOM OF BORING

6" DIA.
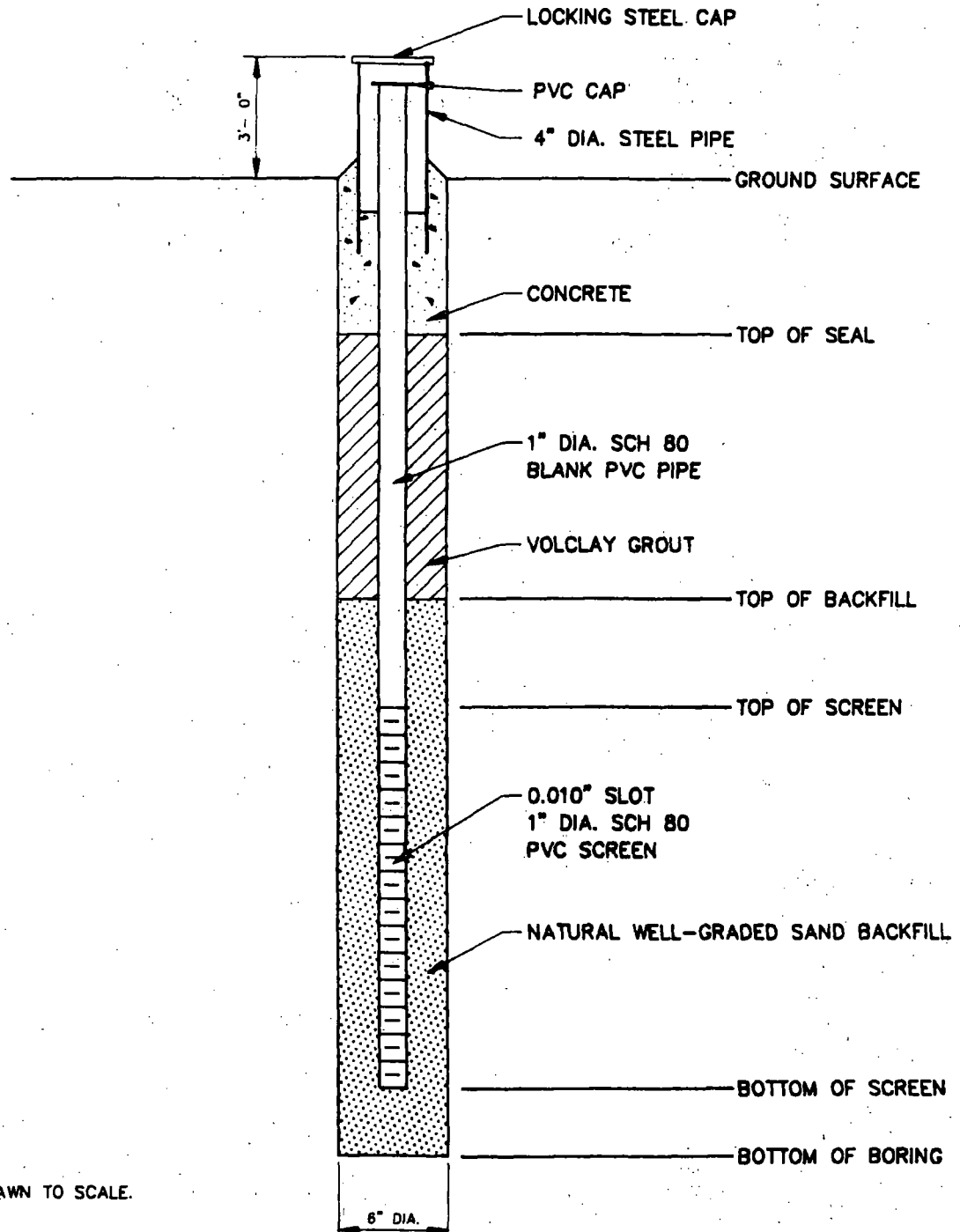
NOTES:

1. NOT DRAWN TO SCALE.

TYPICAL WELL DETAIL

APPENDIX H

LABORATORY FORMS FOR SOILS ANALYSIS

APPENDIX H

LABORATORY FORMS FOR SOILS ANALYSIS

Moisture Content Form
Sieve Analysis and 200 Wash Form
Grain Size Curve
Standard Proctor Form
Consolidation Form
Atterberg Limit Form
Permeability Form

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WATER CONTENT DETERMINATION

PROJECT _____   TESTED BY _____ DATE _____

PROJECT No. _____   CALC. BY _____ DATE _____

BORING No. _____   CHKD BY _____ DATE _____

	TARE NO.								
WEIGHTS (gm)	TARE + WET SOIL								
	TARE + DRY SOIL								
	WATER								
	TARE								
	DRY SOIL								
WATER CONTENT (%)									
SAMPLE									
DEPTH									

	TARE NO.								
WEIGHTS (gm)	TARE + WET SOIL								
	TARE + DRY SOIL								
	WATER								
	TARE								
	DRY SOIL								
WATER CONTENT (%)									
SAMPLE									
DEPTH									

	TARE NO.								
WEIGHTS (gm)	TARE + WET SOIL								
	TARE + DRY SOIL								
	WATER								
	TARE								
	DRY SOIL								
WATER CONTENT (%)									
SAMPLE									
DEPTH									

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PROJECT_____ TESTED BY _____ DATE _____

PROJECT No. _____ CALC. BY _____ DATE _____

BORING No. _____ CHKD BY _____ DATE _____

SAMPLE No. _____ DEPTH_____

SOIL DESCRIPTION _____

TARE No.	
WT. TARE + WS (BEFORE WASH) (gm)	
WT. TARE + DS (BEFORE WASH) (gm)	'
WT. TARE + DS (AFTER WASH) (gm)	
WT. TARE (gm)	

WATER CONTENT

WT. WET SOIL (BEFORE WASH) (gm)	
WT. DRY SOIL (BEFORE WASH) (gm)	
WT. WATER (gm)	
WATER CONTENT (%)	

WT. OF TOTAL SAMPLE DRY (BEFORE WASH) = A (gm) _____ gm

WT. OF TOTAL (+200) SAMPLE = B (gm) _____ gm _____ %

WT. OF TOTAL (−200) SAMPLE = C = A−B (gm) _____ gm _____ %

SIEVE	SIEVE OPENING	ACCUMULATIVE WT. OF SOIL RETAINED (gm)	PERCENT FINER
3"	75.0		
1 1/2"	37.0		
3/4"	19.0		
3/8"	9.5		
#4	4.75		
#10	2.00		
#20	0.85		
#40	0.425		
#80	0.177		
#200	0.075		
PAN	-----		

COARSE_____%

FINE_____%

GRAVEL _____%

COARSE_____%

MEDIUM_____%

FINE_____%

SAND_____%

FINES_____%

___ = _____mm

D_{30} = _____mm

D_{10} = _____mm

$Cu = D_{60}/D_{10}$ = _____

$Cc = (D_{30})^2/(D_{10} \ast D_{60})$ = _____

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Particle Size Distribution

PROJECT_____ PLOTTED BY_____ DATE_____

PROJECT NO._____ CLASSIFIED BY_____ DATE_____

BORING NO. _____ CHECKED BY_____ DATE_____
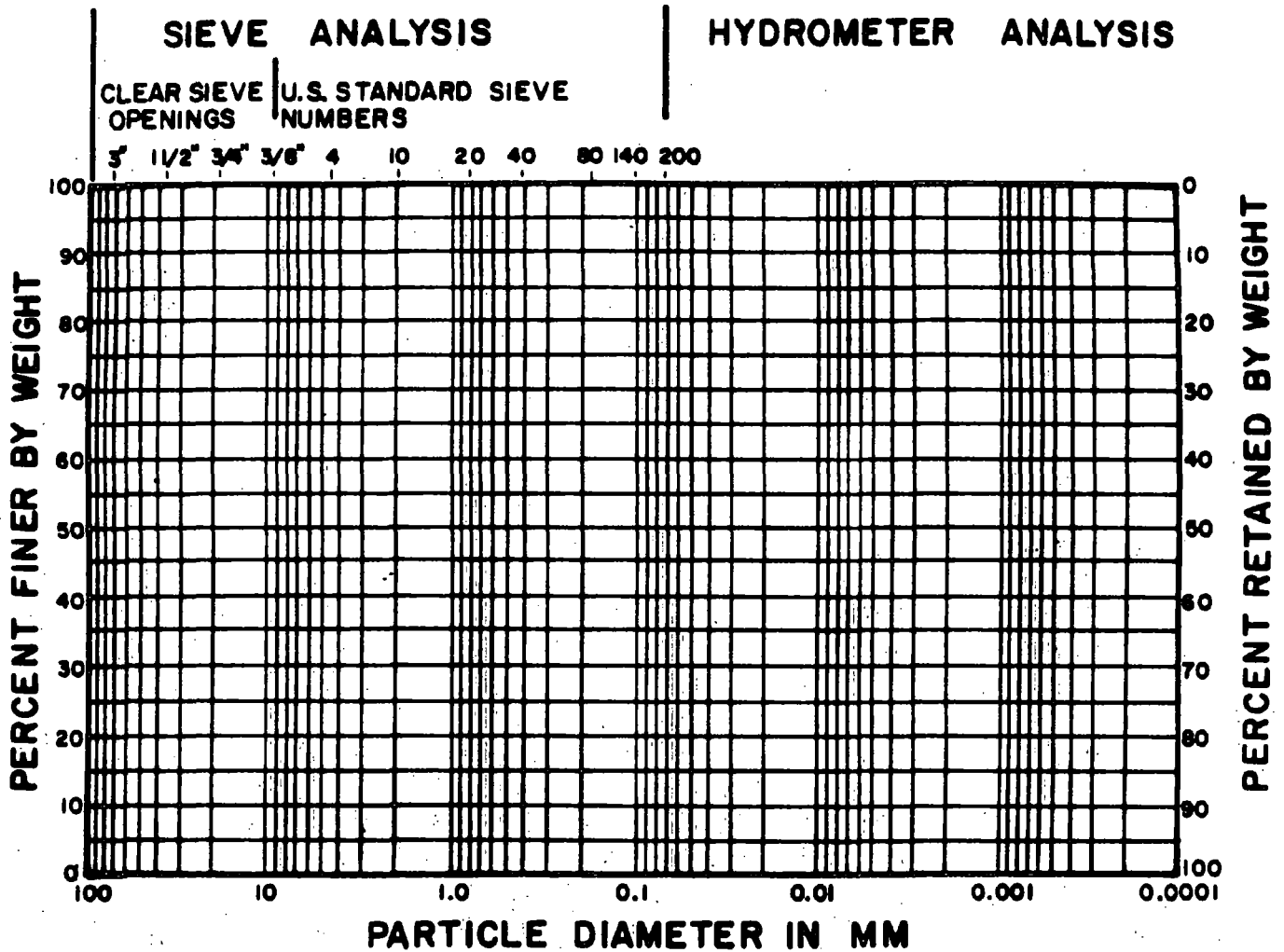
COBBLES	GRAVEL		SAND			SILT AND CLAY FRACTION
	coarse	fine	coarse	medium	fine	

SYMBOL	BORING	SAMPLE	DEPTH	SOIL DESCRIPTION	U.S.C.S	L.L.	P.L	W%

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COMPACTION TEST

PROJECT_____ TESTED BY _____ DATE _____

PROJECT No. _____ CALC. BY _____ DATE _____

BORING No. _____ CHKD BY _____ DATE _____

SAMPLE No. _____ DEPTH_____

SOIL DESCRIPTION _____

BLOWS/LAYER _____ No. OF LAYERS _____ WT. OF HAMMER _____ lb

MOLD DIMENSIONS: DIA. _____ ft.   Ht. _____ ft.   Vol._____ cu ft.

WATER CONTENT DETERMINATION

SAMPLE No.	1	2	3	4	5	6
MOISTURE CAN No.						
WT. OF CAN + WET SOIL						
WT. OF CAN + DRY SOIL						
WT. OF WATER						
WT. OF CAN						
WT. OF DRY SOIL						
WATER CONTENT, w%						

DENSITY DETERMINATION

ASSUMED WATER CONTENT						
WATER CONTENT, w%						
WT. OF SOIL + MOLD						
WT. OF MOLD						
WT. OF SOIL						
WET DENSITY γ,pcf						
DRY DENSITY γd, pcf						

$\gamma d = \gamma/(1 + w)$ (DRY DENSITY EQUATION)

ZERO AIR VOIDS CURVE

$\gamma d = G_s \gamma w/1 + (wG_s/S)$ G_s _____

(ZERO AIR VOIDS EQUATION $S \simeq 100\%$)

w	γd

OPTIMUM MOISTURE = _____ %

MAXIMUM DRY DENSITY = _____ pcf

DENSITY—γd, pcf

WATER CONTENT, w%

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CONSOLIDATION TEST

PROJECT_____

PROJECT NO._____

TESTED BY_____DATE_____

CALC. BY._____DATE_____

CHKD. BY_____DATE_____

LOCATION_____

BORING NO._____SAMPLE DEPTH_____

SAMPLE NO._____

SPECIFIC GRAVITY, G_s._____

APPARATUS MEASUREMENTS

CONTAINER HEIGHT, Z_1,____cm.____in.

CONTAINER DIAMETER____cm.____in.

CONTAINER AREA, A, IN sq. cm.____

STONE + COVER

THICKNESS, Z_2,____cm.____in.

SOLIDS HEIGHT, $2H_o = \dfrac{W_s}{G_s \gamma_w A}$ = ____ cm.____in.

APPLIED LOADS

SIDE FRICTION ALLOWANCE IN %____

_____

_____

DEGREE OF SATURATION IN %

TEST START_____

TEST END_____

WATER CONTENT

BEGINNING OF TEST   END OF TEST

REMARKS:

SPECIMEN LOCATION						
CONTAINER NO.						
WT. CONTAINER + WET SOIL IN g						
WT. CONTAINER + DRY SOIL IN g						
WT. WATER, W_w, IN g						
WT. CONTAINER IN g						
WT. DRY SOIL, W_s, IN g						
WATER CONTENT, w, IN %						

APPLIED PRESSURE IN kg./sq. cm.	SCALE LOAD IN lbs.	FINAL DIAL IN in.	DIAL CHANGE IN in.	Z_3, IN in.	SPECIMEN HEIGHT $2H = Z_1 - Z_2 + Z_3$ IN in.	2H FROM DIAL CHANGE IN in.	VOID HEIGHT, $2H - 2H_o$, IN in.	VOID RATIO, $e = \dfrac{2H - 2H_o}{2H_o}$	FITTING TIME IN sec.		COEF. OF CONSOL., c_v, IN sq. cm./sec.	
									t_{90}	t_{50}	$.848 H^2/t_{90}$	$.197 H^2/t_{50}$

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PROJECT _____ TESTED BY _____ DATE _____

PROJECT NO. _____ CALC. BY _____ DATE _____

BORING NO. _____ DEPTH _____ CHECKED BY _____ DATE _____

TEST LOAD _____

DATE	TIME	ELAPSED TIME, t, min.	$\frac{\sqrt{t,}}{\sqrt{min.}}$	COMPRESSION DIAL, DIV.

DATE	TIME	ELAPSED TIME, t, min.	$\frac{\sqrt{t,}}{\sqrt{min.}}$	COMPRESSION DIAL, DIV.

DIAL READING, DIVISIONS

$\sqrt{\text{TIME, MINUTES}}$

DIAL READING, DIVISIONS
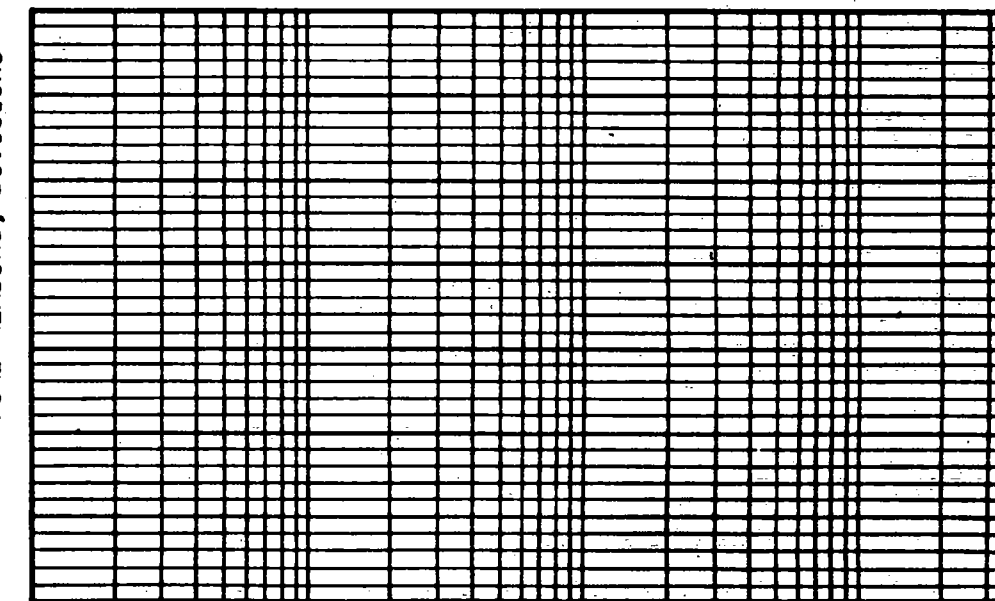
0.1   1.0   10.0   100.0

TIME, MINUTES

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ATTERBERG LIMITS TESTS
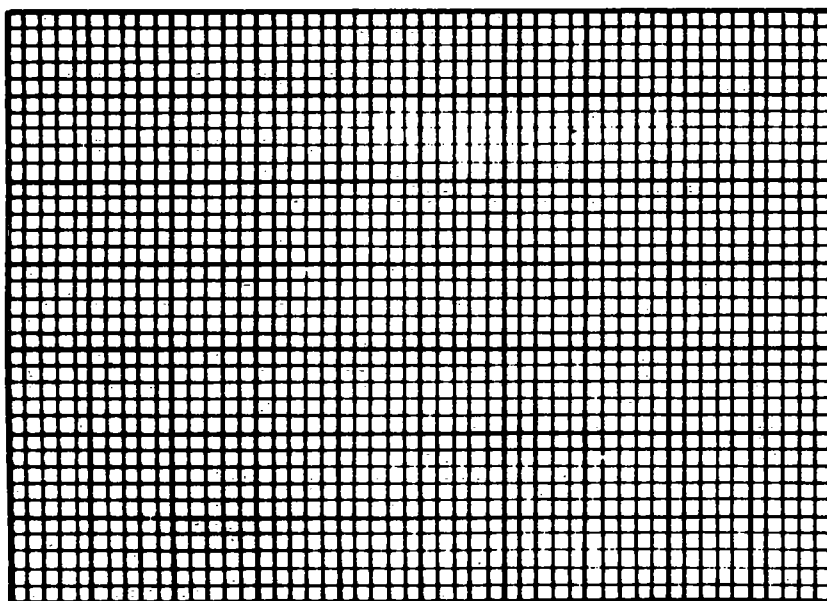
PROJECT _____ TESTED BY _____ DATE _____

PROJECT No. _____ CALC. BY _____ DATE _____

BORING No. _____ CHKD BY _____ DATE _____

SAMPLE No. _____ SAMPLE DEPTH _____

SOIL DESCRIPTION _____ TARE No. _____

LIQUID LIMIT

DETERMINATION No.	1	2	3	4	5
CONTAINER No.					
WT. OF CONTAINER + WET SOIL, gm					
WT. OF CONTAINER + DRY SOIL, gm					
WT. OF WATER, W_w, gm					
WT. OF CONTAINER, gm					
WT. OF DRY SOIL, W_s, gm					
WATER CONTENT, w, %					
No. OF BLOWS					

PLASTIC LIMIT

DETERMINATION No.	1	2	3
CONTAINER No.			
WT. OF CONTAINER + WET SOIL, gm			
WT. OF CONTAINER + DRY SOIL, gm			
WT. OF WATER, W_w, gm			
WT. OF CONTAINER, gm			
WT. OF DRY SOIL, W_s, gm			
WATER CONTENT, w, %			

FLOW CURVE

WATER CONTENT

No. OF BLOWS

UPPER LIMIT LINE = 0.9(LL-8)

A LINE = 0.73(LL-20)

ITY INDEX

LIQUID LIMIT

SUMMARY OF RESULTS

LIQUID LIMIT	
PLASTIC LIMIT	
PLASTICITY INDEX	
NATURAL WATER CONTENT	
USCS SYMBOL	

LABORAT   ABILITY TES:

CEL. _____   PROJECT _____ WAUKEGAN HARBOR _____   PROJECT No. _____ 87-126 _____

SAMPLE I.D. _____   COMMENTS _____

SAMPLE DEPTH _____

PERMEANT _____

DATE	TIME	ELAPSED TIME (hrs)	PRESSURE (PSI)			BURRETTE READINGS				INCREMENTAL		CUMULATIVE			AVG. FLOW RATE (cc/sec)	PORE VOLUME RATIO	K (CM/SEC)
			INFL	EFFL	CELL	INFL UENT No.		EFFL UENT No.		INFL (cc)	EFFL (cc)	TIME (hrs)	INFL (cc)	EFFL (cc)			

TOTALS

SAMPLE LENGTH (CM) _____
DIAMETER (CM) _____
AREA (CMxCM) _____
TOTAL VOLUME (CC) _____
POROSITY _____
PORE VOLUME _____

SAMPLE WEIGHT (GMS)	BEFORE	AFTER
WET		
WET		
DRY		
WT. of WATER		

SPECIFIC   2.60
GRAVITY   2.65
(circle one)   2.70
           2.75
Other _____

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TRIAXIAL CELL PERMEABILITY COMPUTATIONS

PROJECT _____ TESTED BY _____ DATE _____

PROJECT No. _____ CALC. BY _____ DATE _____

BORING No. _____ CHKD BY _____ DATE _____
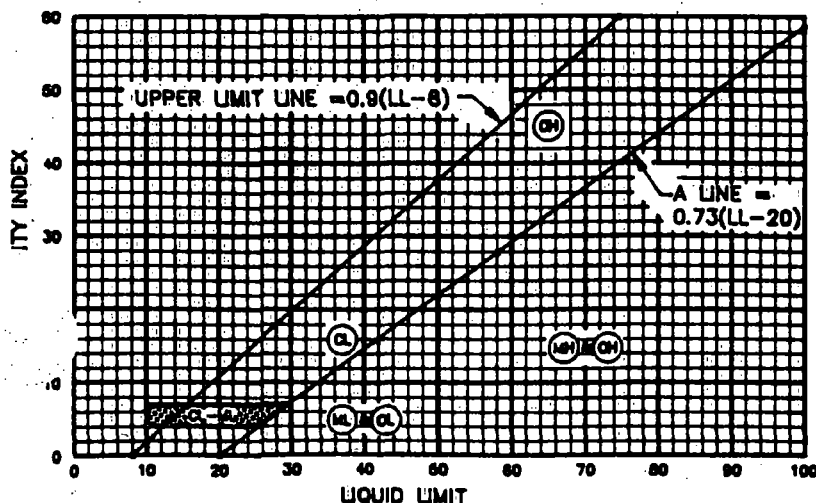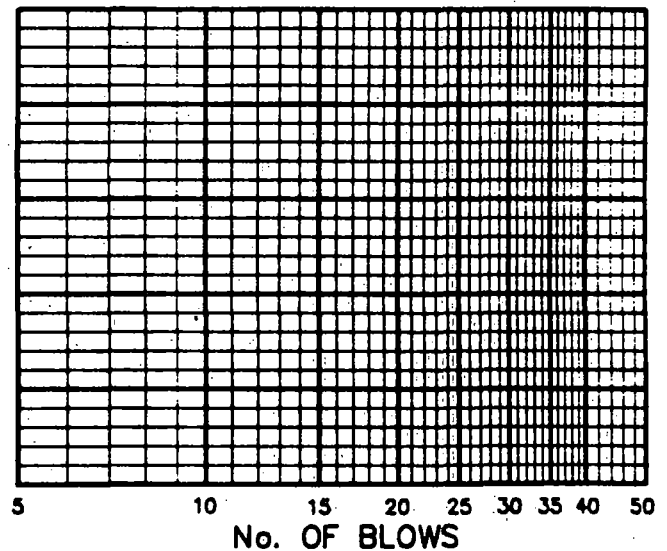
SAMPLE No. _____ SAMPLE DEPTH _____

SAMPLE DATA

	BEFORE TEST	AFTER TEST	% DIFF.
L=LENGTH (cm)			
AVG. DIAMETER (cm)			
TOP AVG. (cm)			
MID AVG. (cm)			
BOT. AVG. (cm)			
A=AREA=$\pi D^2/4$ (cm^2)			
'A			
VOLUME=AxL (cm^3)			

	BEFORE TEST	AFTER TEST	% DIFF.
TARE No.		.	
TARE + WET SOIL (gm)			
TARE + DRY SOIL (gm)			
TARE (gm)			
DRY SOIL (gm)			
WATER (gm)			
WATER CONTENT (%)			
WET SOIL (gm)			
SOIL WET UNIT WT. γ (gm/cm^3)			
SOIL DRY UNIT WT. γd (gm/cm^3)			
SOIL DRY UNIT WT. γd (PCF)			
SATURATION S(%)=V_w/V_v			

SPECIFIC GRAVITY (G_s)= _____

VOID RATIO, e = _____

POROSITY, n = e/1+e _____

PORE VOLUME = SAMPLE VOLUME x n
= _____ cm^3

PERMEABILITY COMPUTATIONS

L = SAMPLE LENGTH		cm
A = CROSS-SECTIONAL AREA		cm^2
INITIAL TIME, t_1		hr.
FINAL TIME, t_2		hr.
ELAPSED TIME, ΔT		hr.
VOLUME OF INFLUENT		cm^3
VOLUME OF EFFLUENT		cm^3
AVERAGE VOLUMETRIC FLOW =		cm^3
Q = AVAERAGE VOLUMETRIC FLOW RATE = V/ΔT (cm^3/hr)		cm^3/hr
Q, cm^3/sec = V/(ΔT x 3600 sec/hr)		cm^3/sec
PRESSURE DIFFERENTIAL, ΔP		lb/in^2
H = DIFFERENTIAL HEAD, cm = $\Delta P/\gamma w$ = $\dfrac{(\quad lb/in^2)(144\ in^2/ft^2)(30.48\ cm/ft)}{62.4\ lb/ft^3}$		cm
COEFFICIENT OF PERMEABILITY = QL/AH (CONSTANT HEAD EQUATION)	k =	cm/sec

APPENDIX I

PACKAGING AND SHIPPING GUIDELINES

Packing and Shipping Guidelines

I. INTRODUCTION

The Federal Regulations set forth by the Department of Transportation (DOT) for the packaging, labeling, and shipping of hazardous materials are extensive and broadly applicable. Therefore, a copy of the DOT requirements as described in the Code of Federal Regulations, 49 CFR 171-177, is an essential reference for those anticipating the need to ship samples of hazardous materials. What follows are generalized guidelines for compliance with DOT standards, along with references to the applicable sections in the Federal Register. It may be prudent to check with state and local agencies for any additional requirements or restrictions they may have.

II. SAMPLE TYPES

In selecting the proper shipping procedures, it should first be decided which of the two basic categories the sample falls into: Environmental Sample or Hazardous Substance Sample. An additional need for this distinction is to provide bases for selecting health and safety precautions for the laboratory personnel receiving and handling the samples.

A. Environmental Samples - These are samples of soil, water, or air usually collected off-site of a hazardous waste dump or chemical spill, and are therefore not expected to be contaminated with high concentrations of toxic materials. The function of "environmental sample" collection is usually to monitor the extent of contamination and/or the off-site transport of contaminated materials. If there is doubt as to the suitability of a sample to this classification, it should be placed in the Hazardous Substance category.

B. Hazardous Substances - Samples falling into this group are known or expected to be contaminated at concentrations that are potentially harmful; including, but not limited to, on-site samples of soil or water, samples from drums or bulk storage tanks, contaminated pools, lagoons, etc., and leachates from hazardous waste sites.

These are operational definitions intended to aid in making decisions concerning sample handling and shipping. The specifics of the DOT definitions are found in 40 CFR 261.3, and 261.4.

III. ENVIRONMENTAL SAMPLES

Although packaging and shipping requirements for environmental samples (associated with hazardous waste situations) are not as stringent as for hazardous waste samples, it is recommended that the following general packing procedure be utilized to ensure safe delivery and maintain sample integrity. This becomes especially important when samples are being transported by common carrier. If sufficient information is available concerning the nature of the sampled material, the following may be relaxed accordingly.

SHIPPING OF ENVIRONMENTAL SAMPLES

When a sample is shipped to the laboratory, it must be packaged in a proper shipping container to avoid leakage and/or breakage. A cardboard box that will provide at least 10 cm (4 inches) of tight packing around the sample container must be used. Acceptable packing materials include sawdust, crumpled newspaper, vermiculite, polyurethane chips, etc. Other samples that require refrigeration must be packed with reusable plastic packs or cans of frozen freezing gels in molded polyurethane boxes with sturdy fiberboard protective case. The boxes must be taped closed with masking tape or fiber plastic tape.

All packages must be accompanied by a sample analysis sheet and chain-of-custody record. Complete address of the sender and the receiving laboratory must legibly appear on each package. When sent by mail, register the package with return receipt requested. When sent by common carrier, obtain a copy of the bill of lading. Post office receipts and bill of lading copies may be used as part of the chain-of-custody documentation.

It should be noted that the addition of the following "hazardous" compounds as preservatives to environmental samples will not alter the Environmental classifications provided the following criteria are met:

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1. Hydrochloric acid solutions at concentrations 0.04 percent (w/w) or less;

2. Mercuric chloride in water solutions at concentrations less than or equal to 0.004 percent (w/w);

3. Nitric acid in water, concentrations less than or equal to 0.15 percent (w/w);

4. Sulfuric acid solutions, concentrations less than or equal to 0.035 percent (w/w);

5. Sodium hydroxide in water, concentrations less than or equal to 0.080 percent (w/w);

6. Phosphoric acid in water, concentrations yielding a pH range between 4 and 2.

APPENDIX J

FIELD PERMEABILITY TESTS

REPORT DOCUMENTATION PAGE

1. Report No.	2.	3. Recipient's Accession No.
BuMines OFR 136-77		PB 272 452

4. Title and Subtitle	5. Report Date
FIELD PERMEABILITY TEST METHODS with applications to solution mining	August, 1977
	6.

7. Author(s)	8. Performing Organization Report No.
John E. O'Rourke, Randall J. Essex and Barbara K. Ranson	13719A

9. Performing Organization Name and Address	10. Project/Task/Work Unit No.
Woodward-Clyde Consultants #3 Embarcadero Center, Suite 700 San Francisco, California 94111	11. Contract or Grant No. J0265045

12. Sponsoring Organization Name and Address	13. Type of Report
Office of the Assistant Director - Mining Bureau of Mines Department of the Interior Washington, D.C. 20241	Final Report
	14.

15. Supplementary Notes

Approved for release by the Director, Bureau of Mines, Sept. 29, 1977.

16. Abstract

A survey of existing and developing field permeability test methods was conducted in order to identify and specify capable methods to be used in feasibility investigations or performance monitoring for in situ leaching of ore deposits. Geologic settings of leachable deposits are discussed, as well as representative techniques used for the in situ leaching operation. Subsurface investigation techniques including drilling, core recovery, and down-hole inspection methods relevant to field permeability investigations are discussed. Field experience is examined and capable field permeability test methods are identified. Specifications for test borehole preparation, test performance, and methods of analysis are given. The test methods are comparatively rated in a matrix with respect to costs, ease of use, and data effectiveness for a broad range of conditions. Well Pump and Packer test methods receive high ratings. Recommendations are made for needed developments in field permeability test methods and a comprehensive bibliography is given.

17. Originator's Key Words (EJC Thesaurus) Permeability, Field Permeability Tests, Hydraulic conductivity, Pervious Soils, Core Drilling, Fractured Rock Permeability, In situ leaching, Solution mining, Pressure Measuring Equipment, Pump Test, Percolation Tests, Mathematical Analysis 17c. 08I.	18. Availability Statement Release unlimited by NTIS.

19. U. S. Security Classif. of the Report	20. U. S. Security Classif. of This Page	22. Price PC A09 MF A01

i

8.2 CONSTANT HEAD, CONSTANT FLOW AND PACKER TESTS

8.2.1 Background

In this section the borehole, piezometer or pipe into which water is pumped will be called an injection well.

This analysis applies to any pump-in test where a steady state condition is achieved; i.e., both Q, the in-flow, and H, the height of water in the injection well, become constant over time. This analysis, therefore, can be used for constant head tests, packer tests and constant-flow tests.

Several analysis methods are available in the literature; research by Schmid (1967) has shown that there is good agreement among the range of formulas. For example, the variation in value of K computed may vary by a factor of 2 between the methods of analysis developed by Schmid and Hvorslev. Such a variation is within the standard deviation of field test results, even from similar, carefully performed field tests using a single analysis method.

Selected analysis methods are presented in this section. The methods cover both saturated and unsaturated media and a wide variety of well geometries.

In saturated media, Hvorslev (1951) developed the basic analysis for constant head tests. His assumptions are the same as those given for variable head test analyses in Section 8.1.1. The USBR (Earth Manual) analysis method, which is applicable for packer tests, is considered more accurate for tests below than above the groundwater level. Where one or more observation wells are available, Schmid (1967) has developed a solution which gives the permeability over a larger area and is less influenced by local variations in the soil/rock medium. If observation well data is available, it should be used in the permeability calculation. Hvorslev's, the USBR (Earth Manual) and Schmid's analysis methods are presented.

Other analyses available in the literature include those by Cornwell (in Zangar, 1953), which is similar to Hvorslev's, by Gibson, whose solution is modified to account for the compressibility of soils, and by Hvorslev (1951) who provides solutions for linear or sinusoidual fluctuation in base groundwater levels.

Two methods are presented for unsaturated media; for a zone above the water table saturated by capillary action and for an unsaturated material overlying on impermeable bed (USBR,G-97).

8.2.2. Analysis Methods

1) Determine Steady State Conditions

Let H = height of water in well above base of test zone

    Q = flow rate of water

    t = time

To determine whether the test is in Zone 1 or Zone 2, calculate:

$$Y = \frac{H + D_W}{L}$$

$$X = \frac{H}{H + D_W}$$

Then enter Figure 8-4 with X and Y to determine the Zone.

iv) Determine the constant head H_C for calculations.

Zone 1: $H_C = H$

Zone 2: $H_C = \dfrac{(H + D_W) + (H - L)}{2}$

Zone 3: $H_C = H - H_W$

v) To compute the shape factor F for a given test well geometry and test
zone in constant head tests using data only from the test well, refer
to Figures 8-5 through 8-9 for the USBR G-97 method, to Figure 8-10
for the USBR Earth Manual method (packer test only), or to Figure 8-11
for Hvorslev's method. Figures 8-5 through 8-7 require supplemental
reference to Figures 8-8 or 8-9, which contain graphs for the determina-
tion of conductivity coefficients under saturated and unsaturated con-
ditions, respectively. For the single curve contained in Figure 8-8,
an equivalent equation is presented for the investigator's convenience.
However, Figure 8-9 contains a family of curves, thereby precluding a
simplified analytic representation. Note that the USBR G-97 method for
unsaturated conditions is limited in depth of application as a result
of the limited range of conductivity coefficients presented in Figure
3-9. With regard to the USBR Earth Manual method, the formula is con-
sidered to be more accurate for tests below the groundwater table than
above it. When using Hvorslev's method for anisotropic soils and rock,
the engineer must estimate $m = \sqrt{K_h/K_v}$. If the well is packed with
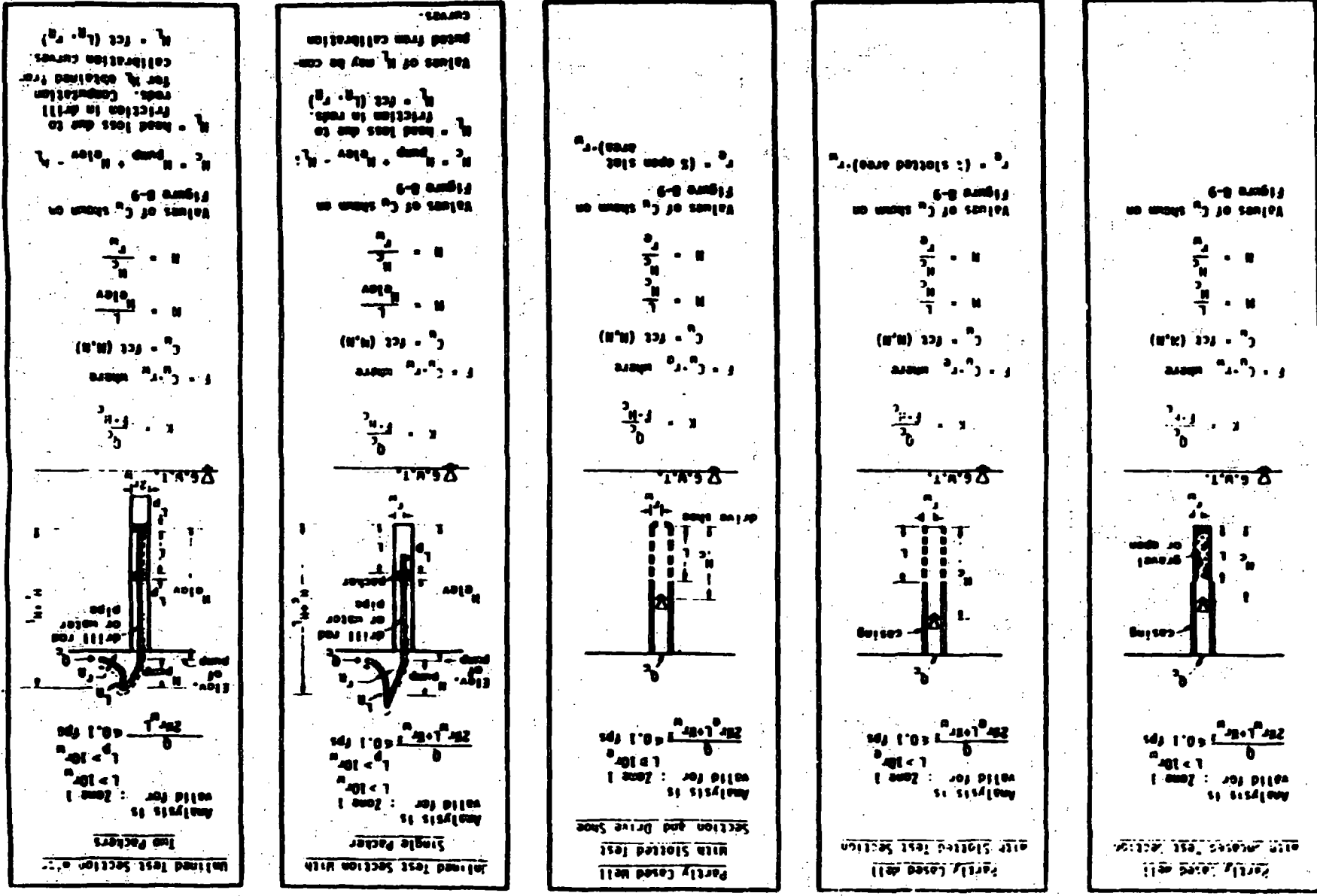gravel, the engineer must also estimate $n = K'_v/K_v$, where:

K_v = the estimated vertical permeability of the rock or soil mass.

K_h = the estimated horizontal permeability of the rock or soil mass.

K'_v = the vertical permeability of the gravel filter in the well
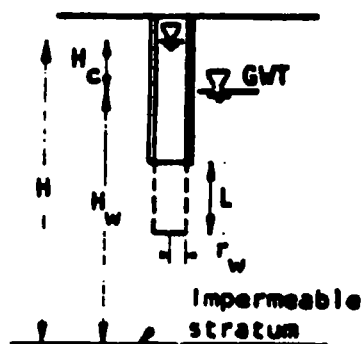(probably at least 10^{-2} cm/sec).

The values of m and n enter into the computation of the shape factor F
in Figure 8-11.

Partly Cased Well With Slotted Test Section	Unlined Test Section with Single Packer	Unlined Test Section With Two Packers

Partly Cased Well With Slotted Test Section

Analysis is valid for : Zone 3

$L > 10r_e$

$$\frac{Q}{2\pi L r_e + \pi r_w^2} \leq 0.1 \text{ fps}$$

$H_w > 5L$

$$K = \frac{Q_c}{F \cdot H_c}$$

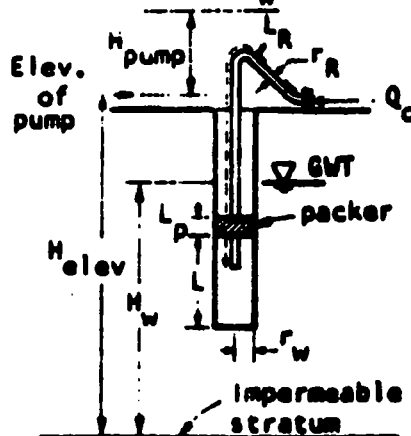$H_c = H - H_w$

$F = C_s \cdot r_e + 4r_w$

where

$r_e = (\text{ open slotted area}) \cdot r_w$

Values of C_s are given in Figure 8-8, or can be approximated from:

$$C_s = 5.30 \left(\frac{L}{r_e}\right)^{0.73}$$

Unlined Test Section with Single Packer

Analysis is valid for : Zone 3

$L \geqslant 10r_w$

$$\frac{Q}{2\pi L r_w + \pi r_w^2} \leq 0.1 \text{ fps}$$

$H_w \geqslant 5L$

$$K = \frac{Q_c}{F \cdot H_c}$$

$H_c = H - H_w$

$H = H_{elev} + H_{pump} - H_L$

where H_L = head loss due to friction in drill rods.

$H_L = fct (L_R, r_R)$ and H_L may be computed based on calibration curves

$$F = (C_s + 4) \cdot r_w$$

Values of C_s are given in Figure 8-8, or can be approximated from:

$$C_s = 5.30 \left(\frac{L}{r_w}\right)^{0.73}$$

Unlined Test Section With Two Packers

Analysis is valid for : Zone 3

$L \geqslant 10r_w$

$$\frac{Q}{2\pi L r_w} \leq 0.1 \text{ fps}$$

$H_w \geqslant 5L$

$$K = \frac{Q_c}{F \cdot H_c}$$

$H_c = H - H_w$

$H = H_{elev} + H_{pump} - H_L$

where H_L = head loss due to friction in drill rods.

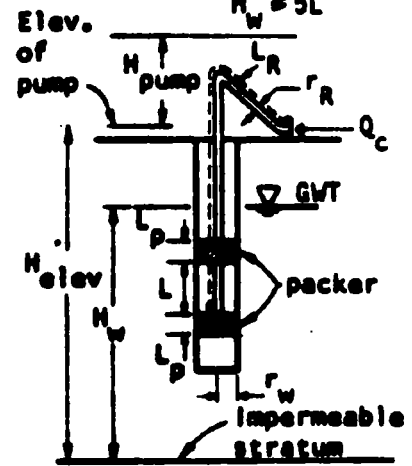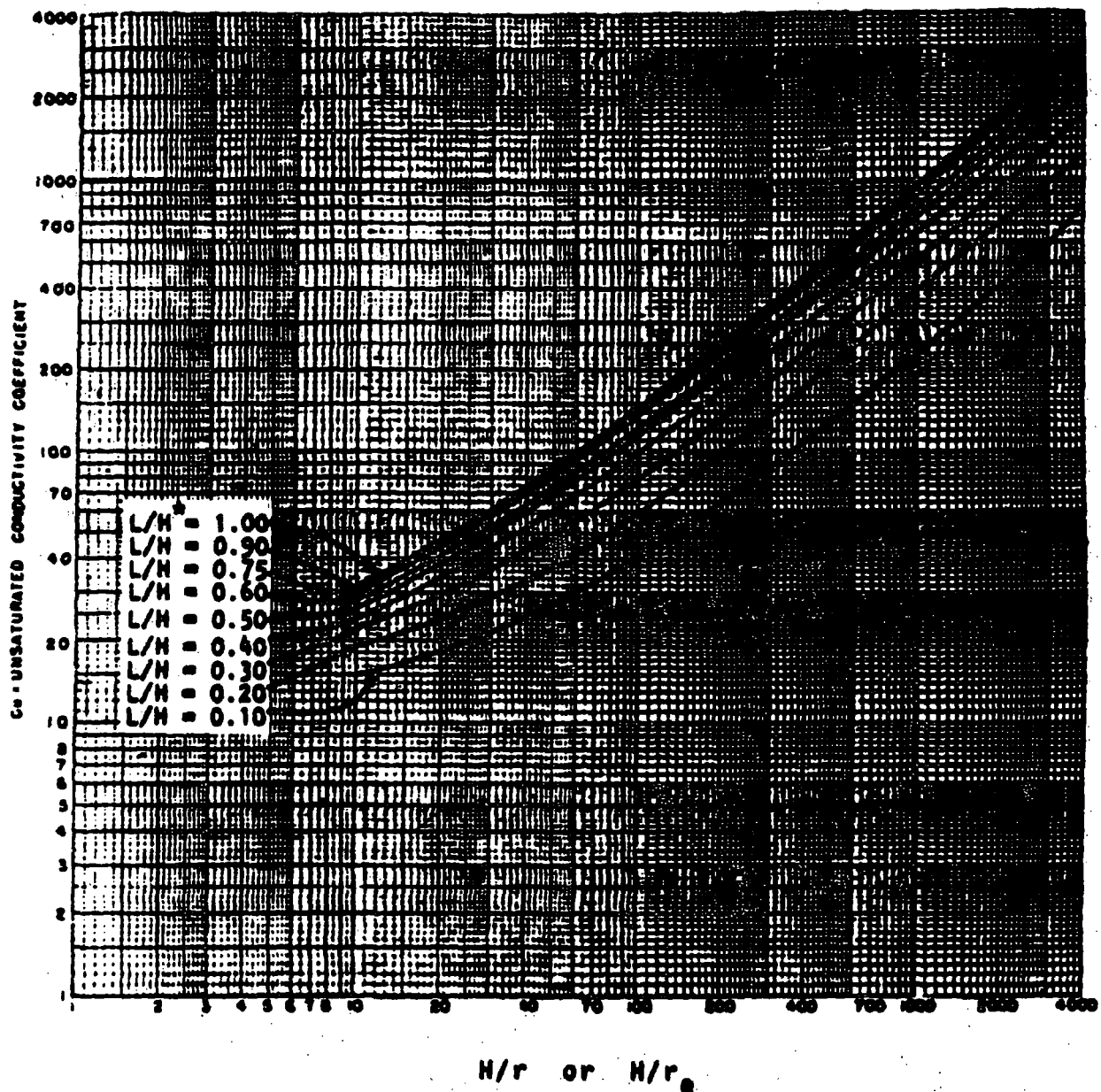$H_L = fct (L_R, r_R)$ and H_L may be computed based on calibration curves

$$F = C_s \cdot r_w$$

Values of C_s are given in Figure 8-8, or can be approximated from:

$$C_s = 5.30 \left(\frac{L}{r_w}\right)^{0.73}$$

Figure 8-7   USBR ANALYSIS METHOD FOR CONSTANT HEAD TEST - ZONE 3 (BELOW WATER TABLE) (after USBR, G-97)

*L/H$_{elev}$ for packer tests

Figure 8-9 C$_u$ VALUES FOR USBR CONSTANT HEAD TEST ANALYSIS
(USBR, G-97)

1   isotropic conditions: $K_h = K_v = K$

a - anisotropic conditions: $K_h \neq K_v$

$$K \text{ or } K_h = \frac{Q_c}{(F \cdot H_c)}$$
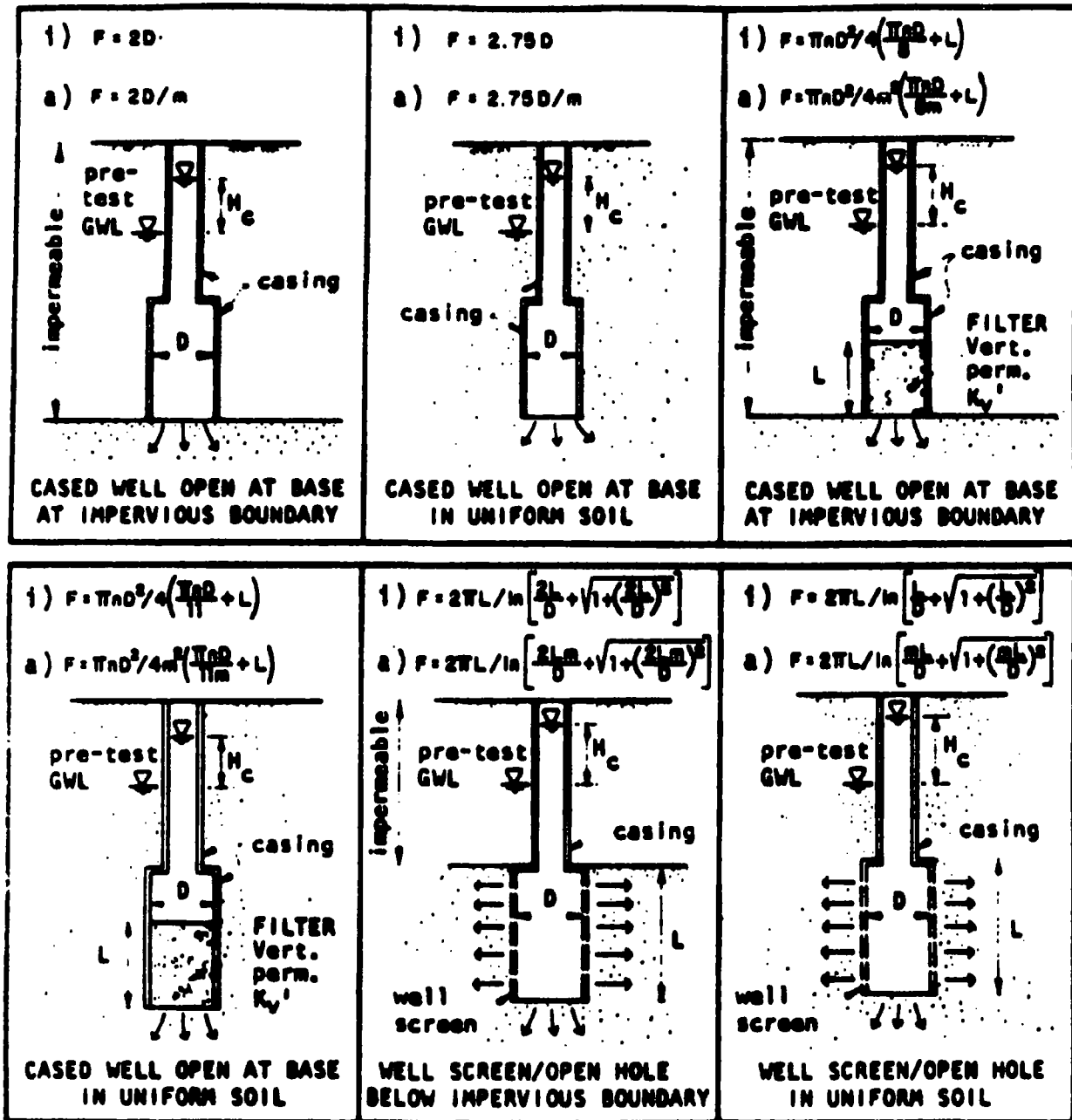
DEFINITIONS: $K_m = \sqrt{K_v K_h}$; $m = \sqrt{K_h/K_v}$; $n = K_v'/K_v$

where K_v = vertical permeability of soil/rock mass

K_h = horizontal permeability of soil/rock mass

K_v' = vertical permeability of filter in casing

Figure 8-11   HVORSLEV'S ANALYSIS METHOD FOR CONSTANT HEAD
TEST - ZONE 3 (BELOW WATER TABLE)
(1951)

HEALTH AND SAFETY PLAN
PRE-DESIGN PHASE
WAUKEGAN HARBOR SITE
WAUKEGAN, ILLINOIS

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HEALTH AND SAFETY PLAN
PRE-DESIGN PHASE
WAUKEGAN HARBOR SITE
WAUKEGAN, ILLINOIS

1.0 INTRODUCTION

The health and safety plan addresses the procedural requirements to protect
workers during the pre-design field exploration activities at the Waukegan
Harbor job site (Site). The specific activities are described in the Work
Plan. The action involves the installation of borings, piezometers,
borehole logging, test pit excavation, well development, site surveying,
and the collection of samples of ground water, soil, harbor sediments, and
recovery of water that has contacted the sediments. This document
describes specific safety procedures which will be utilized for all on-site
personnel involved in the pre-design field activities, including drilling
and excavation subcontractors. The plan will be implemented in accordance
with the OSHA Safety and Health Regulations for Construction, 29 CFR 1926
and OSHA Standards for Hazardous Waste Operations and Emergency Response
(Interim Final OSHA Rule - December 19, 1986), 29 CFR 1910.120.

The plan presents a realistic approach to the anticipated hazards at the
Site, however, site conditions may vary through the duration of the pro-
ject. As actual site conditions change, parts of the plan may be revised
if site conditions warrant. All changes in health and safety measures
specified must be approved by the corporate health and safety officer.
Canonie's corporate health and safety officer is Ms. Irene Fanelli.

All information presented in this plan will be presented and available to
all on-site employees and subcontractors. A copy of this plan will be
available at all times on the Site.

The Canonie site health and safety officer for Phase I, pre-design field
exploration activities, will be Mr. Kevin Brissette. Alternate Canonie
health and safety officers are Mr. Peter Romzick or Mr. Mitch Obradovic.

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The site health and safety officer has the authority and responsibility to implement all aspects of this plan, including termination of all field activities to resolve health and safety issues. The site health and safety officer is responsible for updating this plan with approval from a corporate health and safety officer, as conditions warrant. The project manager has the overall responsibility for the project including health and safety. The project manager remains unchosen at this time.

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2.0 SITE CONTROL

The Site will be divided into an exclusion zone, decontamination zone, and support zone. The zones are defined as follows:

Exclusion Zone - The exclusion zone will be the area within a 50-foot radius of any drilling, test pit, or sampling activities.

Decontamination Zone - A decontamination zone will be located within each of the three containment areas, Figure 1. Because the soil samples are not taken for purposes of chemical analysis, decontamination will occur only at completion of work in a proposed containment area.

Support Zone - The support zone is considered to be the areas surrounding the exclusion zone and the decontamination zone.

Only authorized personnel will be allowed to enter the decontamination and exclusion zones. Such entry will be limited to personnel who have demonstrated compliance with the medical and training requirements for the Site, and who have the required level of protective equipment.

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3.0 HAZARDS ANALYSIS

Outboard Marine Corporation (OMC) used hydraulic oil that contained polychlorinated biphenyls (PCBs). The PCBs are the only hazardous constituent of the oil.

The work activities associated with the exploration program present potential physical and chemical hazards to the workers involved. In all instances, precautionary measures will be implemented to minimize those risks.

3.1 Physical Hazards

As on all construction sites, there is a recognized potential for personal injury due to "struck by/against" accidents. Personal protective equipment will be required to guard against head, foot, and eye injuries.

Test pits will not be excavated to depths exceeding five feet without sloping the sides of the excavation to a slope of 1:1 or more or providing shoring in the test pit. Each test pit will be immediately backfilled and compacted upon completion.

Soil borings will not be drilled within 15 feet of any overhead power lines or any underground utilities, 29 CFR 1926.550(a)(15). All known power lines and underground utilities are shown on Figure 1. The exact location of overhead and underground utilities will be determined by contacting the appropriate utilities prior to drilling or digging.

A potential for elevated noise exposure exists during the drilling operation. This hazard will be controlled through the use of hearing protection such as ear plugs and/or ear muffs as directed by the health and safety officer.

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It is not anticipated that heat stress will be a major consideration during the duration of the pre-design program. The scheduled length of the exploration is eight weeks. Exposure to cold and wet conditions is possible during site activities. All personnel will be made aware of the hazard and advised to wear warm clothing and rain suits. Rain gear will be available for use on-site.

All personnel working over or near water, where the danger of drowning exists, shall comply with U.S. Coast Guard or other safety regulations as may be applicable.

3.2 Chemical Hazards

Based on previous sampling programs, the contaminant of concern at the site is PCBs. PCBs are an oily liquid that have adhered to the sands and sediments at the site. PCBs have a low volatility and therefore the primary exposure is from airborne dust. Airborne PCBs can be irritating to the eyes, nose, and throat. PCBs can also be absorbed through the skin, and can accumulate in the liver and in fatty tissues. PCBs are listed as a toxic substance in the Toxic Substance Control Act. Personal exposures to PCBs will be controlled through the use of personal protective equipment as described in Section 4.0.

4.0 PERSONAL PROTECTIVE EQUIPMENT

Personal protective equipment will be provided for use by on-site person-
nel. Modified Level D protection will be required as a minimum for all on-
site personnel. Air monitoring levels in excess of the action levels
specified, in Section 8.1, will result in Level C protection being
required. All safety equipment will be NIOSH, MSHA approved or in
accordance with 29CFR 1910.134.

The specifics for modified Level D protection are as follows:

1. Hardhat;
2. Neoprene steel-toe boots or work boots;
3. Rubber gloves;
4. Safety glasses;
5. Hearing protection, as required based on OSHA regulations;
6. Polycoated Tyvek coveralls;
7. Flotation vests for work from barges.

In the event the action level is exceeded, it may be necessary to upgrade
the personal protective equipment to Level C.

The specifics for Level C are as follows:

1. Modified Level D protection;
2. PVC rain gear for personnel handling sampling equipment;
3. Dust masks;

Level B protection is not expected to be necessary during the exploration
program. If the site hazards exceed the protection afforded by Level C,
work activities will cease while measures are taken to reduce the specific
hazards.

The designated site health and safety officer will be responsible for determining the appropriate level of protection and may designate more stringent levels than those described, where site conditions warrant such action. The designated site health and safety officer will not reduce protection requirements as defined herein, unless granted approval by the corporate health and safety officer.

5.0 MEDICAL SURVEILLANCE

A medical surveillance program provides a means of selection of employees who are physically able to safely perform the work assigned and monitoring their health on a regular basis.

The program consists of a pre-employment evaluation to determine fitness for the job assignment, annual evaluation based on length of assignment, and an end of employment evaluation. In addition, a special evaluation is warranted upon notification by the employee that he/she has developed signs or symptoms indicating possible exposure to hazardous substances.

Medical monitoring will be implemented for all site personnel. All staff personnel included in an annual medical monitoring program will have had an examination which includes:

1. Medical history;
2. Physical examination;
3. Pulmonary function test;
4. Resting EKG;
5. Urinalysis, including microscopic morphology and dipstick;
6. Seven frequency audiogram;
7. Complete blood count with platelets and differential;
8. SMAC blood chemistry screen;

All personnel employed specifically for the exploration activities and not on an annual program will receive a pre-employment examination. The pre-employment examination will include:

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1. Complete medical history;
2. Physical examination;
3. Pulmonary function test;
4. Resting EKG;
5. Seven frequency audiogram;
6. Urinalysis, including microscopic morphology and dipstick;
7. Complete blood count with platelets and differential;
8. SMAC blood chemistry screen.
9. Chest x-ray: 14-inch by 17-inch posterior/anterior;
10. Lumbar sacral x-ray, two views;
11. Blood level PCBs.

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6.0 EMPLOYEE TRAINING

All personnel on-site will have training and/or prior experience which meets the requirements of 29 CFR 1910.120. The Canonie corporate health and safety training program includes a 40-hour course and an annual 8-hour update training. All technical field personnel are included in the training program. The corporate training program includes the following areas:

1. Chemical hazards;
2. Physical hazards;
3. Toxicology and permissible exposure limits;
4. Personal protective equipment and protection levels;
5. Respiratory protection (29 CFR 1910.134);
6. Air monitoring;
7. Confined spaces;
8. Corporate policies and site management;
9. Supervision of health and safety;
10. Site control;
11. Health and safety plans;
12. Medical monitoring and treatment of injuries;
13. OSHA compliance;
14. Personnel training;
15. Decontamination;
16. Practical exercises;
17. Case histories;
18. Drum handling;
19. Hazardous materials sampling.

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All on-site personnel will receive site-specific training which includes:

1. Site chemical hazards (including acute and chronic effects);
2. Site control and decontamination;
3. Emergency procedures;
4. Protection levels and equipment;
5. Proper use and maintenance of protective equipment.

All regulatory personnel and visitors needing access to the exclusion zone will be expected to demonstrate compliance with these training requirements.

Site safety meetings will be held to apprise personnel of specific hazards, air monitoring results, changes in the Health and Safety Plan, or other topics determined by the corporate health and safety officer. These meetings will be scheduled at the discretion of the health and safety officer, but will be held at the initiation of field exploration, at the time of any crew or subcontractor crew changes, and at least monthly thereafter if exploration activities continue for more than a one-month period.

7.0 DECONTAMINATION PROCEDURES

All drilling and sampling equipment leaving a containment cell will be steam cleaned within the proposed boundaries of the containment cell. The proposed limits of the containment cells are shown on Figure 1. Steam cleaning will be used to remove mud, dirt, and other potential contamination. The equipment will be inspected after cleaning to verify removal of contaminated materials. As a minimum, the personnel performing the steam cleaning will wear rubber boots, gloves, and a rain suit.

All personnel exiting the exclusion zone will follow decontamination procedures at the interface of the exclusion and support zones. The personnel decontamination procedures will be:

1. At the end of each day, all rubber boots, rubber gloves, and rain suits will be cleaned with soapy water and long-handled brushes then rinsed with clean water. The boots and gloves will then be stored in plastic bags or as directed by the health and safety officer.

2. All disposable protective clothing will be removed and placed in plastic bags.

3. The rubber boots, rubber gloves, and rain suits will be inspected for holes or other defects that compromise the integrity of the equipment. If such a defect is found, the article will be discarded in the same manner as disposable protective clothing.

8.0 AIR MONITORING

The vapor pressure of PCBs indicates that there is little possibility of volatilization from exposed soils. However, a portable organic vapor analyzer (OVA) will be available on-site and will be used in a monitor mode to record the volatile organic vapor level during the site work.

The driller, driller's helper, and field engineer will wear personal samplers during the first day of drilling along either the East Containment Cell slurry wall alignment or the Crescent Ditch - Oval Lagoon (West Containment Cell) slurry wall alignment. The samples will be analyzed to verify that workers are not exposed to any levels of PCBs above the action limits. All personal monitoring will be conducted in accordance with NIOSH Method 5503 and analyzed by an AIHA accredited laboratory.

8.1 Work Area Action Levels

8.1.1 PCBs

If the results of the personal monitoring indicate the airborne presence of PCBs in concentrations in excess of 1 mg/m^3, the threshold limit value-time weighted average (TLV-TWA), site activities will cease while operations are evaluated for options to reduce personnel exposures to within the personal exposure limit (PEL). Even if PCB exposure is not at levels of concern, the health and safety officer may designate the use of dust masks in combination with dust control.

8.1.2 Volatile Organic Compounds

If OVA measurements reach 10 ppm Time Weighted Average (TWA) above background for 5 minutes or exceeds instantaneous levels of 100 ppm in the

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breathing zone, employee protection will be upgraded to Level C with use of a half-face respirator with carbon cartridges.

If OVA measurements reach 25 ppm TWA above background for 5 minutes, in the breathing zone, employee protection will be upgraded to Level C with the use of a full-face respirator.

If OVA measurements reach 100 ppm TWA above background for 5 minutes, in the breathing zone, work activities will cease until airborne hydrocarbon levels can be reduced to less than 25 ppm TWA.

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9.0 EMERGENCY PROCEDURES

Local treatment facilities will be designated prior to implementation of on-site activities. Travel routes will also be designated. At least one person on-site or immediately available will have first aid and CPR certification.

Emergency phone numbers and contacts are:

Police	623-2131
Fire	623-2121
Victory Memorial Hospital	360-3000
St. Therese Medical Center	249-3900
Poison Control Center (at St. Therese Medical Center)	360-2470

Canonie Corporate Emergency Contacts:

Canonie Office	219/926-8651
Timothy Harrington - Project Manager	219/926-8651
Irene Fanelli - Corporate Health and Safety	415/347-9205
Susan Walker - Corporate Health and Safety	303/367-4469

A first aid kit will be located in the support zone.

All injured employees will go through decontamination prior to leaving the site for medical treatment, if possible. If decontamination procedures may be expected to further injure or delay critical treatment of the employee, the employee will be transported without decontamination. Medical response personnel will be made aware of the need for decontamination, if necessary.

On-site emergencies are expected to be within the capabilities of on-site personnel. In the event of a fire, accident, or injury, work activities will cease while the emergency is brought under control. Minor injuries to

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on-site personnel will be treated on-site or at the local facility desig-
nated for the Site. In the event of a major injury or where extensive
movement of the worker may cause further injury, local emergency medical
personnel will be contacted. If the worker can be moved out of the exclu-
sion zone safely, efforts will be made to do so. If not, emergency person-
nel will be admitted to assist the employee. Emergency personnel will be
provided with polycoated Tyvek coveralls, disposable boots, and gloves if
contact with PCBs is likely in responding to the emergency.

Any emergency vehicles entering the exclusion zone are expected to encoun-
ter only minimal contamination since site activities will have ceased in
order to tend to the emergency. As such, decontamination should not be a
concern for emergency vehicles, but will be considered on a case-by-case
basis. The immediate life and health of the injured personnel is con-
sidered to be of utmost importance in comparison to decontamination of an
emergency vehicle, since contamination is expected to pose a negligible
risk to the public at large.

10.0   RECORD KEEPING

The record keeping program will consist of the following documents contain-
ing the information described:

1. Training/safety meeting record: This record will include the
   date, topics covered, persons attending, and the signature of the
   person holding the meeting or training session.

2. OSHA 200: This record contains the required information for
   recording on-site injuries and illnesses. This record is gene-
   rated by the corporate health and safety staff, and a copy is
   maintained on-site.

3. Medical records: Employee medical records are maintained by the
   examining physician, and copies are kept at the Canonie corporate
   office. No medical records are maintained on-site.

4. Chain-of-custody: This record is maintained for all soil/water/
   air samples collected for chemical analysis. This record contains
   the name of all individuals who handle a sample, the sample iden-
   tification, analysis requested, and sample destination.

Copies of the forms used for recording training/safety meetings, chain-of-
custody form, and the OSHA 200 form are presented in Appendix A to this
plan.

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11.0 SITE OPERATING PROCEDURES

11.1 General Site Health and Safety and Work Rules

1. No drinking, gambling, or illegal drugs will be allowed on-site. Anyone reporting to work under the influence of alcohol and/or illegal drugs shall be subjected to disciplinary action. Any employee under a physician's care and/or taking prescribed narcotics must notify the designated site health and safety officer.

2. Personal protective equipment is required in designated areas. Such equipment may include, but is not limited to, respiratory protection, earplugs, hardhat, rain suits, boots, gloves, poly-coated Tyvek coveralls, and safety glasses.

3. Eating, drinking, smoking, and chewing gum or tobacco are not allowed inside the exclusion area.

4. Changes in work practices or work rules shall be implemented only after approval by the project manager and the designated site health and safety officer.

5. Construction equipment always has the right-of-way over regular vehicles.

6. All employees must clean up at the end of their shift before leaving the site.

7. All protective clothing required will be supplied by the designated site health and safety officer. None of this equipment will be permitted to leave the site until the completion of the project.

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8. Employees are responsible to clean and maintain the protective equipment issued to them. Any noted defects in the equipment shall immediately be reported to the designated site health and safety officer.

9. Employees shall listen for warning signals on construction equipment and shall yield to construction equipment.

10. All equipment operators shall pay deliberate attention to watching for workers on the ground who may be in their path and provide warning to these people before moving.

11. All workers shall follow emergency procedures explicitly.

11.2 Conditions of Employment

1. All prospective employees must pass a pre-employment physical. Failure to submit to, or pass any exam will be grounds for discharge.

2. All employees must participate in the air quality exposure monitoring program by wearing the personal monitors or sampling devices, if required and specified by the site health and safety officer. Any employee refusing to participate in the program, or who tampers with a sample, will be subject to disciplinary action.

3. All employees must complete a required training program prior to starting work.

4. All employees are required to use the personal protection specified for their work. This may include, but is not limited to, a dust mask, rain suit, gloves, boots, hardhat, hearing protection, polycoated Tyvek coveralls, and safety glasses.

5. All employees must abide by all safety rules and procedures as described in the work rules and/or developed throughout the project.

6. No smoking shall be allowed within 50 feet of drilling or test pit excavation operation. Failure to abide by this requirement shall be grounds for discharge.

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APPENDIX A

RECORD KEEPING FORMS

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CANONIE ENVIRONMENTAL SERVICES CORP.
SITE SAFETY MEETING/TRAINING SESSION LOG

Project No. _____   Date _____

Project Name _____

Topics Discussed _____

_____

_____

_____

Name (Print)	Signature	Employer
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

_____	_____
Name of Trainer or Person Conducting Meeting	Signature

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For Calendar Year 19 ___

INJURIES

ILLNESSES

RECORDABLE CASES

PREVIOUS PAGE TOTALS

TOTALS

POST ONLY THIS PORTION OF THE LAST PAGE NO LATER THAN FEBRUARY 1.

Certification of Annual Summary Totals By _____ Title _____ Date _____

OSHA No. 200

PROJ. NO.	PROJECT NAME		NO.	ANALYSIS														REMARKS
L.P. NO.	SAMPLERS: (Signature)		OF															
			CON-															
DATE	SAMPLE I.D.		TAINERS															

Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Remarks
Relinquished by: (Signature)	Date/Time	Received by: (Signature)	
Relinquished by: (Signature)	Date/Time	Received for Laboratory by: (Signature)	

Canonie Environmental, 212 Frank West Circle, Suite A, Stockton, CA 95206

No 4448

White Sampler   Canary - Return Copy To Shipper   Pink - Lab Copy

DRAFT
OPERATION AND MAINTENANCE PLAN
WAUKEGAN HARBOR SITE
WAUKEGAN, ILLINOIS

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DRAFT
OPERATION AND MAINTENANCE PLAN
WAUKEGAN HARBOR SITE
WAUKEGAN, ILLINOIS

1.0 INTRODUCTION

This document constitutes the Operation and Maintenance (O&M) Plan for the
Waukegan Harbor Site (Site).

When the remedial activities at the Site are complete, three separate soil-
bentonite wall-enclosed containment cells with covers, ground water extrac-
tion wells, ground water piezometers, ground water monitoring wells, and a
water treatment facility will be operated and maintained. The three con-
tainment cells are shown on Figure 1 and are designated as the Slip No. 3
Containment Cell, West Containment Cell, and East Containment Cell. The
containment cells will encompass areas of 1.5 acres, 3.4 acres, and
5.5 acres, respectively, and will be covered with a combination of bitumi-
nous concrete and vegetative covers. Table 1 summarizes the composition of
each cell cover. Ground water extraction wells in each containment cell
will provide an inward hydraulic gradient by maintaining the water level
within the cell at a lower hydraulic level than the natural ground water
level outside the cell. Piezometers within each cell will be paired with a
ground water monitoring well outside the cell. The monitoring well/piezo-
meter pairs will be used to monitor the hydraulic gradient across each
containment cell boundary. The ground water monitoring wells will also be
used for obtaining samples of the ground water immediately outside of each
containment cell soil-bentonite wall. The ground water treatment facility
will treat the ground water extracted from each containment cell prior to
discharge into Lake Michigan.

The operation and maintenance of the water extraction and treatment system,
containment cell caps, and ground water monitoring system will continue for
the period provided by Section V.D.9 of the Consent Decree. The program
will include a regular inspection and monitoring schedule as described in
the following section. An indication of PCBs in the monitoring well system
will be assessed under the compliance procedures in Section 4.0, and if the

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results indicate the soil-bentonite wall is failing to operate as designed, the wall will be repaired subject to approval of the United States Environmental Protection Agency (U.S. EPA). The operation and maintenance program is subject to modification pursuant to Section V.D.9 of the Consent Decree.

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2.0 MAINTENANCE OF FINAL COVER AND INSPECTION

The top surface of the final cap will consist of either bituminous concrete or top soil overlying a synthetic drainage layer and an HDPE synthetic liner. The top surface of the cap will be inspected in accordance with the following schedules, and repairs will be completed as soon as practical, weather conditions permitting, after discovery of need for repair. Inspections will provide a regular documented method of insuring the integrity of the protective cover.

2.1 Inspection Schedule

If a bituminous concrete cover is installed, it will be inspected each spring during the post-closure care period. Cracks will be sealed with asphalt sealer. Potholes or other deterioration of the asphalt surface will be repaired using procedures recommended by the Asphalt Institute in MS-16 (Asphalt Pavement Maintenance, 1967).

If a vegetation and topsoil cover is installed, it will be mowed twice per growing season and fertilized annually in the spring of each year during the post-closure care period. In addition, the vegetative cover will be inspected every three months during the first two years after completion of closure, semi-annually for the next two years and each spring during the remainder of the 30-year post-closure care period.

Any gullies or washes in the top soil cover will be backfilled, compacted, reseeded, and mulched with straw. Any areas of dead vegetation will be similarly treated. Lined or riprapped drains will be installed if persistant erosion recurs in the same location.

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If it is necessary to excavate into the containment cell or if damage otherwise occurs to the drainage layer or synthetic liner, the following repair procedures will be followed.

1. The synthetic surface will be exposed and inspected for signs of physical damage (punctures, slits, or tears). This may require cutting and removing or rolling back the synthetic drainage materials.

2. The liner will be exposed at least 12 inches in all directions from the damaged area.

3. In the case of a puncture, the damaged area will be repaired by the application of extruded material or a glued patch.

4. For a tear, slit, or large puncture, the flaw will be overlain by a panel of the same material which will be bonded to the existing liner by an extrudate weld or by glueing.

5. The extrudate weld or glued seam will be checked using a vacuum box.

6. The synthetic filter or drainage layer will be replaced and fastened in place to the existing drainage layer.

3.0 GROUND WATER MONITORING

At least 12 ground water monitoring wells will be sampled and analyzed for PCBs on a quarterly basis for the first two years and semi-annually for the remainder of the post-closure period. Analysis for PCBs will be by gas chromatograph U.S. EPA Method 608.

The ground water monitoring wells will be installed after completion of the soil-bentonite slurry wall at each containment. The wells will be labeled with permanent weatherproof designations. Background analysis will be established by the first four quarterly seasonal samplings occurring after well installation.

Ground water sampling will be completed as follows:

1. The water level in the well will be measured and recorded using an electric tape.

2. The electric tape will be rinsed with deionized water between wells.

3. A sampling pump will be used to evacuate at least three well volumes of water. The purge water will be discharged on the ground surface unless previous sampling indicated PCB levels of more than 0.010 ppm. Water which cannot be discharged on the ground will be recharged into the containment extraction wells.

4. A pre-cleaned one liter glass bottle will be filled with water, sealed, and transported to a laboratory which meets the quality assurance standards for U.S. EPA Method 608.

5. The recharge rate of the well will be recorded for up to one hour.

The record keeping and chain-of-custody requirements for the sampling program are in Appendix A.

The ground water elevations in each of the piezometer/ground water monitoring well pairs will be measured quarterly and recorded on the ground water elevation monitoring log, Table A-3. The measurements will be used to control the extraction well pumps so that a hydraulic gradient differential is maintained across the containment cell soil-bentonite wall. The frequency of measuring and recording will be reduced, as approved, if the rate of change in water elevations is less than an average of six inches per month.

The ground water monitoring wells will be sounded annually to determine if the well is open. Sounding will be completed with a string and steel weight. The weight will be washed with distilled water between wells and the string will be discarded.

Ground water protection monitoring, compliance monitoring, and corrective action programs will be completed as follows:

1. Hazardous Constituents - Ground water monitoring will be for PCBs and chlorinated organics per 40 CFR 761.75. The only other ground water monitoring will be monitoring for pH, conductivity, and temperature completed during the purging of the monitoring wells. If the B.E.S.T. solvent extraction process is used for treating soils, the monitoring program for the West Containment monitoring wells shall include triethylamine.

2. Point of Compliance - The compliance boundary will be a vertical plane located approximately 20 feet from the soil-bentonite walls

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enclosing each in-place containment. The boundary may be closer or farther from the wall in certain locations to account for proximity to structures or other obstructions. Each monitoring well located on the compliance boundary will be paired with a piezometer installed approximately 5 feet inside the soil-bentonite wall so that the differential water level across the soil-bentonite wall may be determined.

3. <u>Compliance Period</u> - The operation and maintenance program will proceed as provided in Section V.D.9 in the Consent Decree and shall be modified or terminated in accordance with that section.

4. <u>Detection Monitoring</u> - Water samples will be analyzed for PCBs by U.S. EPA Method 608 during detection monitoring. The detection limit will be 1 ppb. Reported values for PCBs of 1 ppb to 5 ppb above background will be noted for reassessment at the next moni-toring event. PCBs results of more than 5 ppb above background will be verified by resampling and analysis within two weeks of receiving the laboratory results. A second result greater than 5 ppb above background will shift the ground water monitoring program into a compliance monitoring mode.

If the detection monitoring results indicate that the PCB level is consistently above the background level by less than 5 ppb and shows a continued increase at a rate of 1 ppb/quarter or more for three consecutive quarters, then the ground water monitoring program will move into compliance monitoring.

The U.S. EPA will be provided written notification of a shift to compliance monitoring and a plan for the compliance monitoring within four weeks of confirmation that compliance monitoring is required. If the detection monitoring change in PCB level is

greater than 10 ppb, then the U.S. EPA shall be notified by phone within 24 hours of confirmation of the detection monitoring results.

5. Compliance Monitoring - Compliance monitoring will be completed through the installation of additional monitoring wellpoints along the compliance boundary and may include monitoring points beyond the compliance boundary, if applicable. The locations and construction details for the additional ground water monitoring points will be submitted to the U.S. EPA for approval prior to implementation of compliance monitoring. The results of the compliance monitoring program will be used to determine if PCBs are migrating from the in-place containment area and will be used to assess the location from which the PCBs are emanating.

6. Corrective Action Program - The corrective action program may include repair of the soil bentonite wall by re-excavation and reinstallation, drilling and grouting, vibratory beam grouting, or other repair methods. The details of the proposed corrective action including the quality control and assurance procedures and the monitoring procedures required to verify the corrective action will be submitted to the U.S. EPA for approval prior to implementation. In the event that a delay in implementing the corrective action may result in an imminent release threatening public health and safety, the corrective action will be implemented immediately without seeking the approval of the U.S. EPA.

Corrective Action will begin within 60 days of receiving U.S. EPA approval for corrective action.

The U.S. EPA will have access to observe the regular sampling and to obtain
split samples during regular well sampling. The U.S. EPA will have access
at other times if first pre-arranged with owner by written request, and if
owner is allowed to observe and enforce compliance with proper sampling and
to obtain split samples.

3.1 Monitoring Well Maintenance

The elevation of the reference point on each monitoring well will be resur-
veyed at least once every five years. The top elevation will also be
resurveyed if modifications are made to the well or if the well is inad-
vertently damaged.

A well which becomes filled with sediment as measured by soundings or has
poor hydraulic performance will be cleaned by flushing with potable water.
Sampling will not occur for at least one month after flushing of the well.
If the well continues to perform poorly, the well will be replaced by
installing a new well within 25 feet of the existing well and by decommis-
sioning the former well in accordance with Illinois Administrative Code,
Chapter I, Part 920.120, "Abandoned Wells".

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4.0 GROUND WATER EXTRACTION, TREATMENT, AND DISCHARGE

Ground water will be extracted from each containment cell at a rate which maintains an inward hydraulic gradient across the soil-bentonite wall. Average daily flow will be approximately 500 gallons per day and will likely be pumped and processed by intermittent pumping from the extraction wells.

The pumps will be inspected annually to insure that all high and low set points are operable and that the pump is in running condition. If pumping the well does not reduce the water level in the containment, the pump will be removed and the well screen cleaned with hydrogen peroxide or another oxidizer.

Extracted ground water will be processed through the long-term water treatment facility. The long-term water treatment facility will be a cartridge filter and two carbon adsorption treatment containers connected in series. If the system is running, a sample will be taken monthly pursuant to Appendix B, at a sampling point between the two carbon units. The first carbon container will be replaced, in the manner discussed below, when the PCB level between the carbon contactors exceeds 0.001 ppm for three consecutive sampling dates, as described in the Work Plan.

If the pump and treatment system is run on an intermittent basis, the treatment system will be hydraulically tested before start-up with either lake water or potable water. The test will consist of pumping water through the treatment system at the same pumping rate as occurs during dewatering. The pressure drops through the system will be assessed to determine if the treatment equipment is ready for water treatment.

If the system is run on an infrequent basis, at least one water sample will be collected between the two carbon canisters at both the start and end of the operation.

Carbon replacement will occur by switching the lead-lag sequence. The backup carbon contactor will be placed first in line, and a new carbon canister will be placed in the second or lag position. The exhausted carbon will be containerized, manifested, and transported for appropriate disposal, in accordance with federal, state, and local regulations.

The treatment system will be located within a secondary containment area with a detection sump. If water spills from the carbon canisters or the connecting piping, a high level alarm in the detection sump will cut off electrical power to all extraction well pumps and will provide an alarm sign to a designated operator or guard.

Treated ground water will be discharged to Lake Michigan immediately after treatment at an approved location or to the North Shore Sanitary District.

5.0 REPORTING

Monitoring results from the ground water monitoring wells and the extrac-
tion well treatment system will be submitted to the U.S. EPA on a quarterly
basis for the first two years and a semi-annual basis thereafter. The
results of cover inspections, extraction well maintenance, and treatment
system maintenance will be included with the reports on a yearly basis.

Reports will be issued within 45 days of receipt of each ground water
monitoring test result. Reports on the operation of the water treatment
system will be issued on a semi-annual basis. The discharge limits in the
water treatment reports will be certified by a corporate officer or his
approved designee.

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TABLE 1

CONTAINMENT CELL COVER COMPOSITIONS

Containment Cell	Bituminous Concrete Acres	Vegetation Acres	Total Area Acres
Slip No. 3	To be determined during final design		1.5
West			3.4
East			5.5
			10.4

Note: All surface area values are approximate.

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SITE PLAN
WAUKEGAN HARBOR, WAUKEGAN, ILLINOIS
PREPARED FOR

MARTIN, CRAIG, CHESTER AND
SONNENSCHEIN - CHICAGO, ILLINOIS

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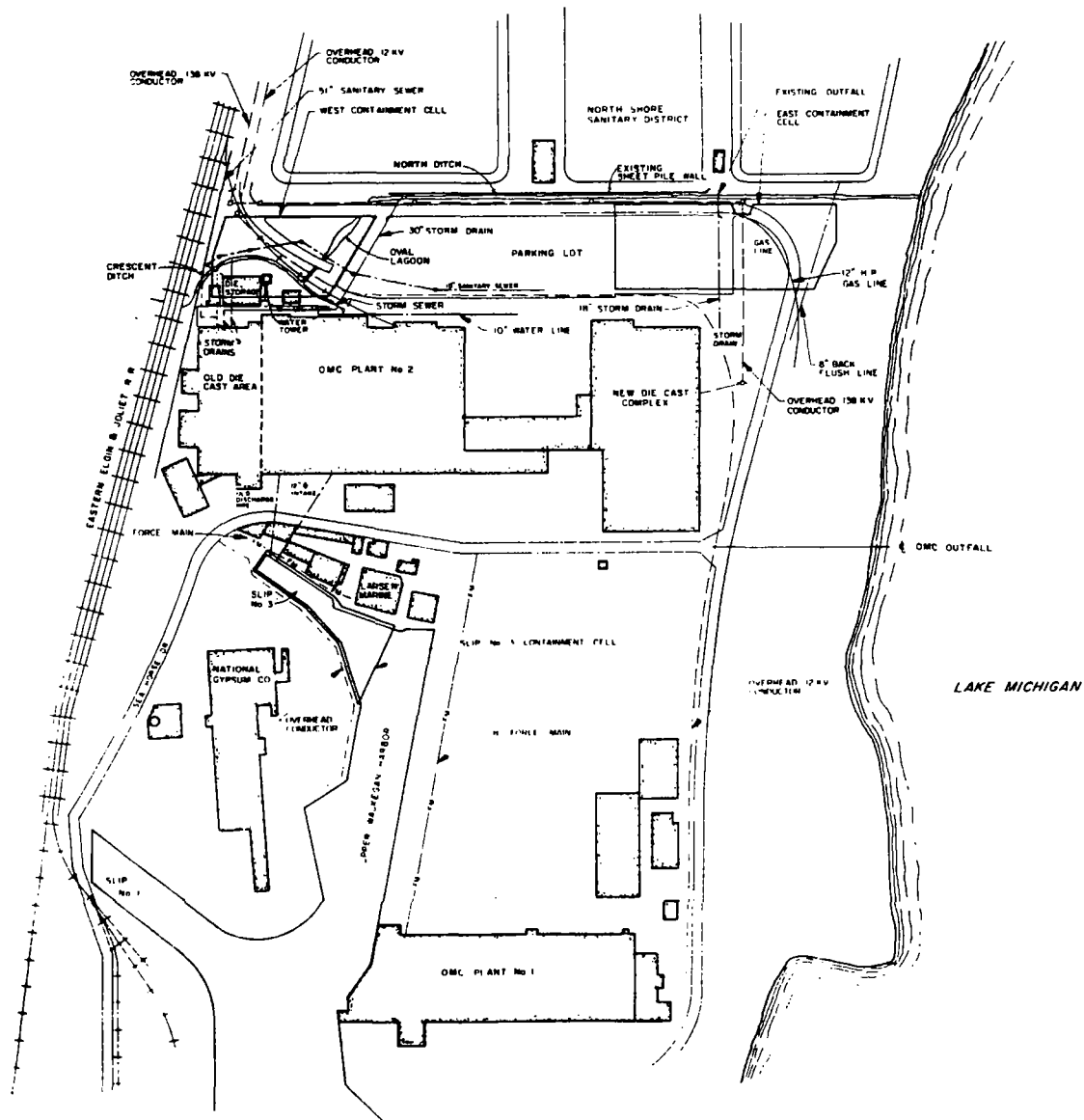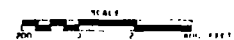
| DATE 1-23-88 | FIGURE 1 | DRAWING NUMBER |
| SCALE AS SHOWN | | 86-059 E76 |

APPENDIX A

RECORD KEEPING REQUIREMENTS

1.0 GROUND WATER MONITORING

The ground water monitoring record keeping forms are found in Tables A-1
through A-3. Table A-1, Field Sample Data, and Table A-2, Well Development
Log, are used concurrently for recording pertinent information during the
purging and sampling of a monitoring well. Table A-3, Ground Water Eleva-
tion Monitoring Log, is used for recording ground water level information
of the monitoring well/piezometer pairs.

1.1 Well Purging and Sampling

Immediately prior to purging each well, the depth from top of well casing
to top of water surface and to bottom of well will be determined to the
nearest 0.05 foot and recorded as a portion of the well sample data (see
Tables A-1 and A-2). Jetting methods will not be used for purging the
monitor wells. The method for purging and sampling of the monitoring wells
is with dedicated submersible bladder-type pumps providing a uniform rate
of discharge. Teflon tubing will be used for intake/discharge lines as
required for sample pump operation. All monitoring wells will be capped
and locked to prevent unauthorized access to the well and the possible
contamination of the well between sampling episodes.

Monitoring wells will be purged by removing at least three well volumes
determined as the total depth of the well minus the depth to the water
surface times the area of the well.

At each well to be sampled, purged waters will be monitored during purge
for temperature, pH, and conductivity as a function of time (see
Table A-2). This data will be accurately recorded such that the variation
of parameters may be related to elapsed purging time. These relationships
along with sample data from selected purge evaluation wells will be used to
establish specific purging volumes for each well. Purging methods,

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volumes, times, and any other pertinent information will be recorded and reported by the sampling team (see Tables A-1 and A-2).

The ground water samples will be placed in glass bottles fitted with caps having Teflon-faced silicon seals. The sample bottles will be one liter in size. Each sample bottle will be labeled with the following:

1. Name of sampling team;

2. Site name;

3. Location identification;

4. Sampling date.

The water sample, when collected, will totally fill the sample bottle. Samples will be placed in an ice chest or similar container capable of maintaining an even temperature while the samples are transported to the laboratory. The packaging and shipping procedures will be in accordance with the accepted standards for the type of analysis requested. Two separate sample bottles of ground water will be collected at each monitoring well as the sample set, so that duplicate samples are available for QA analysis, if required.

1.2 Quality Assurance

An established program of sample chain-of-custody procedures, that is followed during sample collection and handling activities in both the field and laboratory operations, is required to assure that sample integrity is maintained and data generated through the analysis of the samples is applicable to evaluation of the site. The sample custody program as well as the quality assurance procedures regarding the construction water treatment facility water samples will be utilized for the ground water monitoring samples. These procedures will be in the Quality Assurance Project Plan

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(QAPP) for the Waukegan Harbor Site. The QAPP will be prepared during the design phase.

Laboratory QA data and other supporting data will be maintained in accordance with the Consent Decree.

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FIELD SAMPLE DATA

PROJECT No. _____

FIELD ENGINEER _____

PAGE _____ OF _____

PROJECT NAME _____ DATE _____

FIELD DATA:

WELL SAMPLED

[ ]

TOP OF CASING ELEVATION _____

DEPTH TO GROUND WATER FROM T.O.C., FT. _____

GROUND WATER ELEVATION _____

PURGE DATE _____

PURGE METHOD _____

START PURGE _____ ELAPSED TIME _____ HRS. VOLUME PURGED _____
(SEE WELL DEVELOPMENT LOG FOR PURGING DETAILS)

SAMPLER TYPE _____ : 1. SUBMERSIBLE PUMP 2. BLADDER PUMP 3. BAILER
4. OTHER(SPECIFY) _____

SAMPLER MATERIAL _____ : 1. STAINLESS STEEL 2. TEFLON 3. PVC
4. OTHER(SPECIFY) _____

TUBING MATERIAL _____ : 1. TEFLON 2. POLYETHYLENE 3. TYGON 4. SILICON
5. OTHER(SPECIFY) _____

SAMPLE APPEARANCE _____

SAMPLE pH _____ TEMPERATURE _____ SPECIFIC CONDUCTANCE _____

COMMENTS:

WEATHER: _____

OTHER: _____

_____

_____

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TABLE A-2

WELL DEVELOPMENT LOG

PROJECT No. _____

WELL No. _____

FIELD
ENGINEER _____

PAGE _____ OF _____

PROJECT NAME _____ DATE _____

DIAMETER OF WELL (d), INCHES . . . . _____

TOTAL DEPTH OF WELL FROM T.O.C., FEET . . . . . _____

HEIGHT OF GROUND WATER COLUMN IN WELL (W), FEET . . . _____

MINIMUM QUANTITY OF GROUND WATER
TO BE PURGED (Vw, WHERE Vw = $0.12(d)^2$ W), GALLONS . . . _____

PUMPING EQUIPMENT USED _____

WEATHER _____

TIME	PUMPING RATE (GPM)	TOTAL VOLUME (GAL)	pH	TEMP °C	SPECIFIC CONDUCTANCE μMHOS	NOTES

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TABLE A-3
GROUND WATER ELEVATION MONITORING LOG

PROJECT No. _____

FIELD ENGINEER _____

PAGE _____ OF _____

PROJECT NAME _____ DATE _____

WEATHER _____

MONITORING WELL				PIEZOMETER				$\triangle$* (FT.)
MONITORING WELL No.	T.O.C.	DEPTH TO WATER (FT.)	TOP OF WATER ELEV.	PIEZOMETER No.	T.O.C.	DEPTH TO WATER (FT.)	TOP OF WATER ELEV.	

* $\triangle$ = TOP OF WATER ELEV. (MONITORING WELL) − TOP OF WATER ELEV. (PIEZOMETER)

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